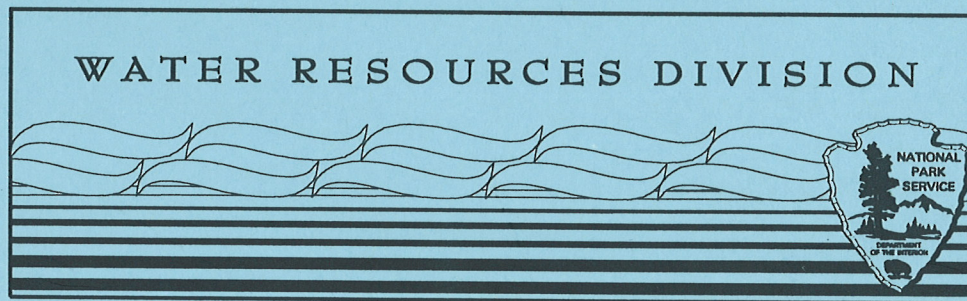


**HYDROLOGIC RESTORATION OF A WET PINE SAVANNA
AT MOORES CREEK NATIONAL BATTLEFIELD**

NORTH CAROLINA

Scott W. Woods and Joel Wagner

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HYDROLOGIC RESTORATION OF A WET PINE SAVANNA AT MOORES CREEK NATIONAL BATTLEFIELD, NORTH CAROLINA

by

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December 2001

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EXECUTIVE SUMMARY

Since 1996 the NPS Water Resources Division, the U.S. Environmental Protection Agency (Region IV), the North Carolina Heritage Program, and The Nature Conservancy have been working with Moores Creek National Battlefield to restore an artificially drained meadow just west of the park visitor center. The goal is to restore the site to a pine savanna wetland complex. This goal is consistent with the park's objective to reestablish the landscape that likely existed at the time of the Battle of Moores Creek in 1776, while preserving the rare native plant species found at the site.

After preliminary studies and compliance requirements were completed, the park implemented an experimental hydrologic restoration in November 1998. The key to the experiment was to block and backfill a portion of a drainage ditch in order to simulate its removal. The objectives of the study described in this report were to determine: 1) whether the experiment restored the site's hydrologic regime; and 2) whether the restored conditions are suitable for reestablishing pine savanna plant communities, including wet pine savanna habitat. The key findings, conclusions and recommendations of the report are as follows:

1. The experimental restoration has stopped the artificial drainage caused by the ditch, and has reestablished the hydrologic connection between the hillslope behind the visitor center and the lower meadow. The net effect of the experimental restoration is a statistically significant increase in water levels throughout most of the meadow in the post-restoration period.
2. Comparisons of post-restoration water levels at Moores Creek with hydrologic data from an undisturbed savanna reference area (Shoestring Savanna in the Green Swamp) indicate that the restored meadow water levels fluctuate in the same range as undisturbed wet, mesic, and dry pine savanna habitats. Specifically, the majority of the upper and lower meadow areas could now support wet to mesic pine savanna

communities (given the appropriate fire regime). Mesic to dry savanna conditions prevail on the margins of the meadow where water table depths are slightly greater.

3. Maps showing areas with similar water table depths for the restored site are presented to guide future reintroduction of native bunchgrasses and other pine savanna species.
4. Recommendations are provided for permanently eliminating artificial drainage and restoring pre-disturbance pine savanna hydrology at Moores Creek National Battlefield.

1.0 INTRODUCTION

Pine savannas include some of the most floristically diverse plant communities in temperate North America. More than 40 species per square meter have been recorded in seasonally wet pine savannas – the highest species richness recorded in the Western Hemisphere at that scale (Walker and Peet, 1983; Peet and Allard, 1993). Prior to European settlement, pine savannas covered approximately 10 million hectares (25 million acres) in the southeastern United States (Society of Range Management, 1974). However, due to the combined effects of agriculture, grazing, timber harvesting, and fire suppression, only approximately 1.2 million hectares (3 million acres) now remain (Outcalt and Sheffield, 1996). The area of pine savanna containing generally intact understory vegetation is considerably less, at just 0.5 to 0.8 million hectares (1.2 to 2.0 million acres) (Noss, 1989).

Staff at Moores Creek National Battlefield in eastern North Carolina have been working with the NPS Water Resources Division (WRD), The Nature Conservancy (TNC), the North Carolina Heritage Program, U.S. Environmental Protection Agency Region IV, and others to restore an artificially drained wet meadow that lies immediately west of the Park's visitor center. Prior to human disturbance, most of the meadow would have cycled through a successional sequence of wet pine savanna – shrub-scrub pocosin – bottomland forested wetland, with fire as the critical determinant of the seral stage at any given time (McCrain and Church, 1985, Pelej, 1997). Drainage via a ditch and tile system, mowing, and other management activities since the early part of the 20th century have converted the site to a partially drained wet meadow dominated by weedy herbaceous species and some woody plant species. However, portions of the site still harbor relic populations of pitcher plants (*Sarracenia* spp.) and state threatened species such as Carolina bog mint (*Macbridea caroliniana*) and spring flowering goldenrod (*Solidago verna*). Based on the available literature and an evaluation of present day site conditions, the project participants have determined that the site should be restored to a pine savanna wetland complex. This is consistent with the Park's objective to reestablish the landscape that existed at the time of the Battle of Moores Creek (1776), while preserving the rare native plant species still represented at the site.

In 1996 the National Park Service and its cooperating partners began a series of actions designed to restore the drained meadow at Moores Creek to a pine savanna wetland complex. The major actions and findings to date are as follows:

- In 1996 fourteen observation wells and two staff gages were installed to collect information on site hydrology under the existing (disturbed) and future (restored) conditions. Park staff began biweekly monitoring of water levels in the wells and staff gages in December 1996. Water level monitoring has continued to the present.
- In 1997 a preliminary assessment of existing vegetation was conducted, including a map of vegetation communities, observations of rare species, and identification of relic savanna/pocosin species. Recommendations were developed for a prescribed burn sequence that would help control invasion of weedy species and promote recovery of native savanna or pocosin plants. Experimental plugging of the ditch outlet to simulate permanent hydrologic restoration of the site was proposed.
- In November 1998 the experimental restoration was implemented, and is still in effect. The experiment involved blocking and backfilling a portion of the ditch at a location that would simulate its removal. A drain that channeled parking area runoff into the ditch was relocated by park maintenance staff prior to the experiment in order to better simulate the pre-disturbance hydrologic conditions. The existing well and staff gage network was monitored throughout the course of the experiment.
- In 1999 the NPS funded TNC to establish long-term vegetation monitoring plots that would be used to periodically evaluate the response of the vegetation communities (including rare species) to restoration activities.
- In 2000 TNC published its report “Establishment of Vegetation Monitoring Protocols and Management Recommendations for the Restoration of a Wet Pine Savanna at Moores Creek National Battlefield” (Crichton and Sutter, 2000). The report

documented the baseline vegetation characteristics and provided detailed protocols for future monitoring to track vegetation response to restoration actions. The study found that some elements of the vegetation community are responding rapidly and positively to the restoration experiment (and the simultaneous cessation of most mowing). In particular, undesirable woody plants such as blackberry and sweetgum are declining, and the Carolina bogmint is now thought to be one of the largest and highest quality populations in the world. A key negative finding was that the characteristic savanna bunch grass species, including wiregrass (*Aristida stricta*), savanna muhly (*Muhlenburgia expansa*), Carolina dropseed (*Sporobolus pinetorum*) and toothache grass (*Ctenium aromaticum*) show no sign of re-colonizing the site. In addition to being an important component of pine savanna vegetation communities (Outcalt et al., 1999), these grass species provide a critical fuel source for the fires that sustain pine savanna ecosystems (Clewell, 1989). The report concluded that hydrologic restoration and planned prescribed burns are not sufficient to support recruitment and establishment of these key grass species. They do not spread vegetatively and are not expected to re-colonize the site from seed in the foreseeable future. Restoration of the savanna bunch grasses, which is critical to the park's goal of restoring an exemplary assemblage of native, endemic and rare savanna species, will require planting of nursery stock.

1.1 PURPOSE AND OBJECTIVES OF THE STUDY

The hydrologic monitoring described above has provided two years of water level data from the pre-restoration experiment period (December 1996 to November 1998) and two years of data from the post-restoration experiment period (December 1998 to December 2000). A critical element of the restoration process is to determine whether plugging the ditch has restored the site's hydrologic regime, and whether the restored hydrologic conditions are suitable for reestablishing pine savanna plant communities. The objectives of the present study were therefore to:

1. Document changes in the hydrologic regime resulting from the restoration experiment and determine if plugging the ditch has had the desired result of removing the drainage effect and raising the water table.
2. Identify appropriate reference sites for pine savanna wetland communities in eastern North Carolina that have hydrologic data, and compare the post-restoration hydrology of the Moores Creek site to those reference sites.
3. Provide hydrologic data needed for subsequent restoration activities, such as determining suitable locations for planting bunch grasses and other native species, and developing a prescribed burn plan.

2.0 STUDY AREA

Moore's Creek National Battlefield is located in Pender County on the Coastal Plain of eastern North Carolina (Figure 1). This 87-acre National Park Service unit borders on Moore's Creek, a tributary of the Black River, which is part of the larger Cape Fear watershed. The National Battlefield was established in 1926 to commemorate the decisive 1776 Battle of Moore's Creek Bridge, in which less than 1000 Patriots defeated more than 1600 Loyalist troops (Hunter, 1994).

The proposed wetland restoration site lies immediately west of the National Battlefield's visitor center and approximately 400 feet from Moore's Creek. At the time of the battle the site was most likely predominantly bottomland hardwood forest and wet pine savanna (McCrain and Church, 1985; Pelej, 1997). The dominant tree and shrub species would likely have included longleaf pine (*Pinus palustris*), pond pine (*Pinus serotina*), fetterbrush (*Lyonia lucida*), loblolly bay (*Gordonia lasianthus*), wax myrtle (*Myrica cerifera*), red bay (*Persea borbonia*), gallberry (*Ilex coriacea*), American holly (*Ilex opaca*), sweetgum (*Liquidambar styraciflua*) and black gum (*Nyssa sylvatica* var. *biflora*).

Drainage via a ditch and tile system, mowing, and other management activities since the early part of the 20th century have converted the site to a partially drained wet meadow dominated by mostly weedy herbaceous species, sweetgum and briars (*Rubus* spp.). However, since the site is maintained as open meadow and wet conditions still exist in some areas, small portions of the site harbor relic savanna and pocosin species such as switchcane (*Arundinaria tecta*), titi (*Cyrtilla racemiflora*), yellow pitcher plant (*Sarracenia flava*), red chokeberry (*Aronia arbutifolia*), meadow lovegrass (*Eragrostis refracta*) and three-awn grass (*Aristida virgata*). Several rare species such as Carolina bog mint (*Macbridea caroliniana*), spring flowering goldenrod (*Solidago verna*) and Carolina Grass of Parnassus (*Parnassia caroliniana*) have been noted in poorly drained depressions in the meadow (Crichton and Sutter, 2000). *M. caroliniana* and *S. verna* are listed as species of special concern in North Carolina. *P. caroliniana* is considered endangered in North Carolina and is a federally listed species of concern.

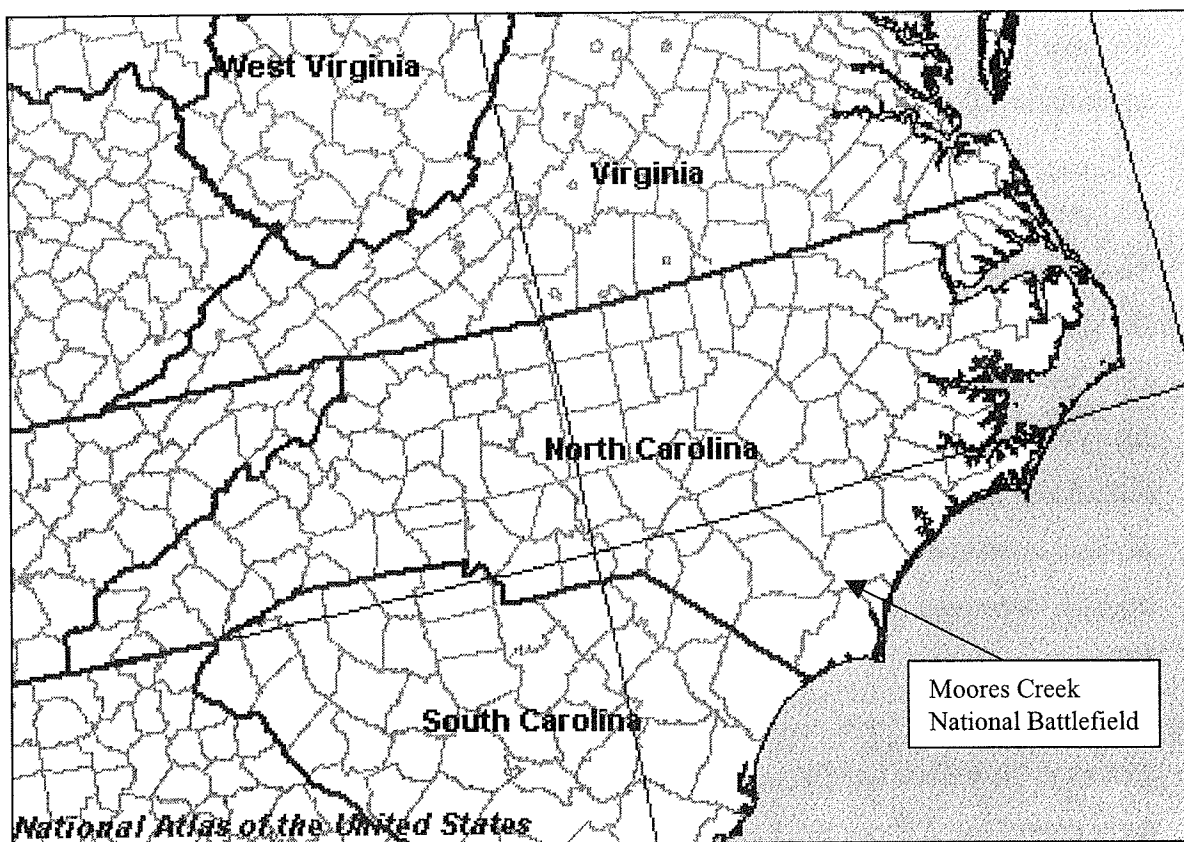


Figure 1. Location of Moores Creek National Battlefield in Pender County, North Carolina.
Base map obtained from National-Atlas.gov website.

The mean annual precipitation at the Wilmington 7 climate station, which lies approximately 20 miles from Moores Creek National Battlefield, is 57.1 inches. The mean monthly precipitation ranges from 3.1 inches in November to 8.5 inches in July (Figure 2). Mean monthly temperatures range from 44°F in January to 79°F in July, and the frost free season extends from early April to late October in most years (USDA, 1990). Monthly potential evapotranspiration (PET), as determined using the Thornthwaite Method, ranges from 0.4 inches in January to 6.2 inches in July. The only month with a precipitation deficit is June, which has an average of 5.5 inches of PET compared to an average monthly rainfall of 5.1 inches. Due to its location near the southeastern part of the Atlantic seaboard, the study area is periodically affected by tropical storms and hurricanes.

Soils at the Moores Creek restoration site are characteristic of the Ocilla, Blanton and Paxville soil series (Spruill, 1997). These soil series have previously been described in Bladen County, which lies immediately adjacent to Pender County (USDA, 1990). Ocilla-like and Blanton soils occur in the drier parts of the site. They are moderately well drained and support hydrophytic vegetation but they lack wetland hydrology and hydric soils indicators. Paxville soils occur in the wetter areas. In their natural state these are typically very poorly drained soils that developed in loamy marine sediments on slopes of 0-1 percent. The water table depth in Paxville series soils is typically less than 12 inches between November and April, and the soil is classified as hydric (USDA, 1990). Paxville soils are wet ultisols, one of three general soil types known to support wet pine savannas in North Carolina (Schafale, 1994).

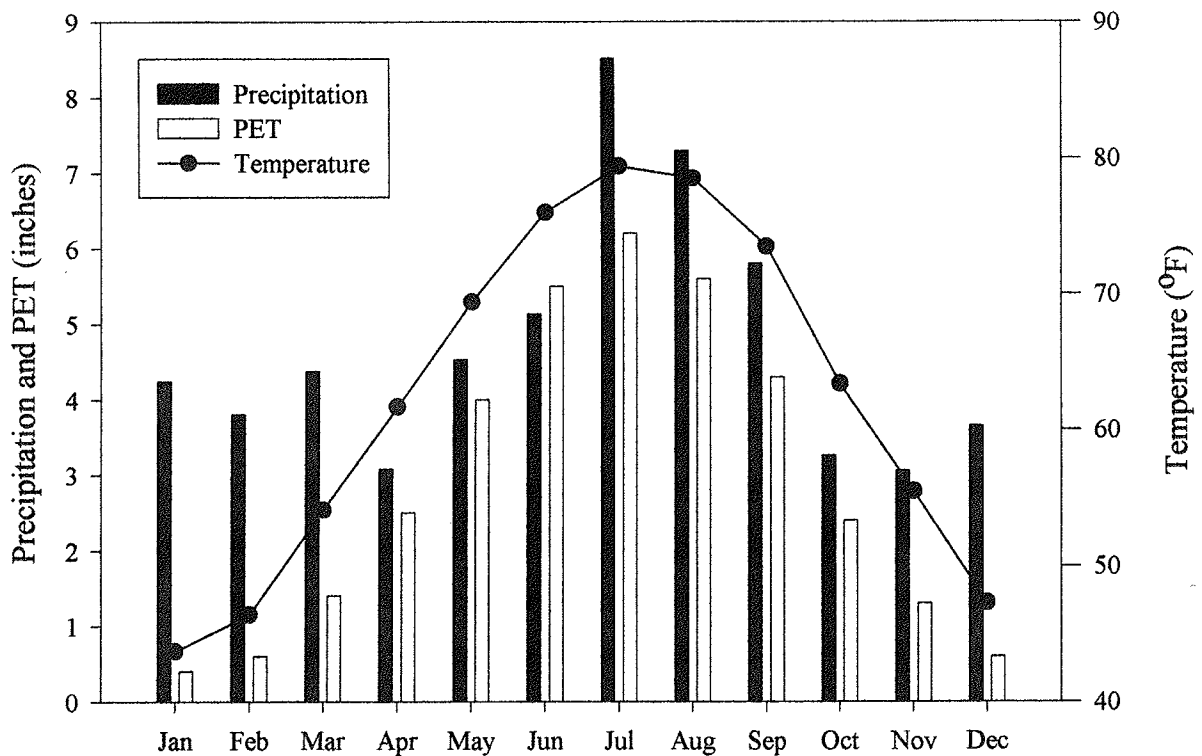


Figure 2. Monthly mean precipitation and potential evapotranspiration (PET) in inches and temperature in degrees Fahrenheit (°F) at Wilmington 7 climate station, based on period of record 1948-2000.

3.0 METHODS

3.1 WELL AND STAFF GAGE INSTALLATION AND MONITORING

Fourteen monitoring wells and two staff gages were installed in the restoration site in early December 1996 (Wagner and Martin, 1997). Well and staff gage locations were chosen so as to optimize the spatial coverage of the site and are shown in Figure 3. Wells 13 and 14 served the additional purpose of providing water level data in areas occupied by rare plant species.

Borings for the monitoring wells were hand-augured to a depth of 4-5 feet and then backfilled with 3-4 inches of medium sand. The wells were made from 2-inch diameter, Schedule 40 PVC pipe, slotted in the lower 18 inches and wrapped with shop cloth over the slotted section. After inserting the well pipe the borings were backfilled to the surface with a mixture of native soil and bagged sand. The wells were developed by flushing them with water until they ran clear. The two staff gages were installed near the upstream and downstream ends of the ditch, and consisted of wooden stakes driven 2-3 feet into the substrate.

Horizontal and vertical coordinates for all wells and staff gages were obtained by surveying with a total station. In addition, coordinate data along 12 transects were used to create a topographic map of the site. These data included 440 ground points, the location and configuration of the ditch, and the approximate location of the tile drain system. All coordinates were established with reference to a local datum.

Park personnel began biweekly monitoring of the water levels at the wells and staff gages in mid-December 1996. Water levels in the wells were recorded as the distance from the top of the well casing to the water surface. Water levels at the staff gages were recorded as the distance from the top of the stake to the water surface. These values were subsequently converted to water level elevations and depths relative to the ground surface using the survey data.

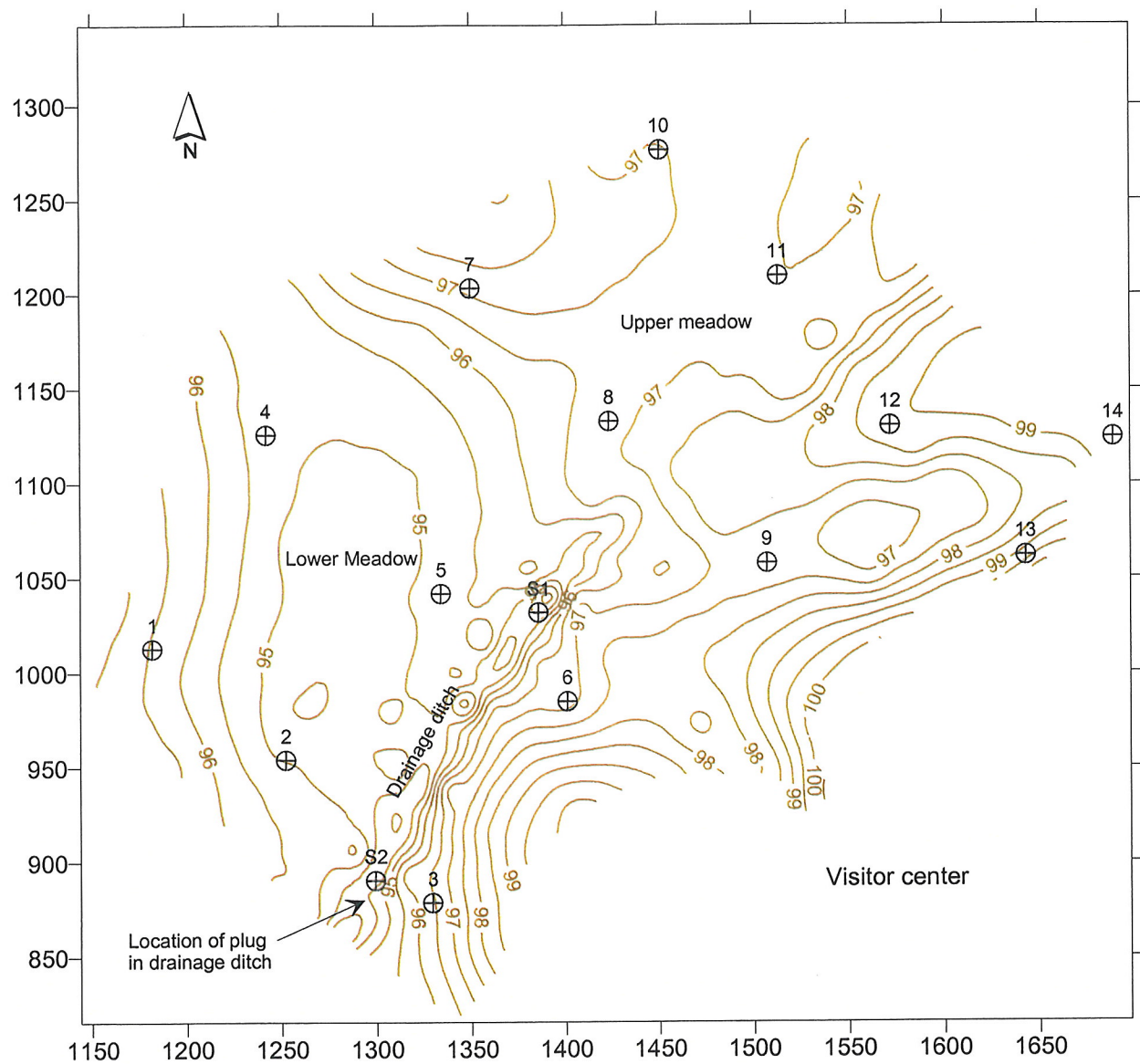


Figure 3. Map of restoration site at Moores Creek National Battlefield. Crossed circles indicate locations of wells and staff gages. Ground surface contour elevations are in feet relative to a local datum.

3.2 EXPERIMENTAL HYDROLOGIC RESTORATION

In November 1998 an experiment was initiated to simulate the removal of the drainage ditch at the southern end of the restoration site. The ditch was blocked at the location shown in Figure 3, and partially backfilled to the point where it enters a culvert under the History Trail at the south end of the site. In addition, a drain that channeled parking area runoff into the ditch was relocated so as to better simulate the pre-disturbance hydrologic conditions. Biweekly monitoring of the wells and staff gages, which at that time had been conducted for approximately two years, continued after the restoration. The only periods without monitoring data occurred when the restoration area was temporarily inaccessible due to flooding during and after two exceptionally large storm events.

3.3 HYDROLOGIC DATA ANALYSIS

Precipitation data obtained from the Wilmington 7 climate station of the National Weather Service were used to determine the comparability of the pre-restoration and post-restoration monitoring periods in terms of the annual and monthly precipitation totals. The Wilmington 7 station has a record of precipitation extending from 1948 until the present. Data on the occurrence of tropical storms and hurricanes along the eastern seaboard of the United States were obtained from the Colorado State University Atmospheric Sciences Department's web-site (<http://typhoon.atmos.colostate.edu>).

Several statistical and non-statistical hydrologic techniques were used to compare the hydrologic conditions at the site in the two years (1997 and 1998) preceding and the two years (1999 and 2000) following the experimental restoration. The water level data for each well were first tested for normality using the Kolmogorov-Smirnov one sample test. If the data were normally distributed, t-tests were used to compare the mean depth to the water table in each of the fourteen wells in the pre-restoration and post-restoration monitoring periods. If the data were not normally distributed then the non-parametric Wilcoxon signed rank test was used instead of the t-test. The null hypothesis for both tests was that the means were not significantly different. The alpha level for the tests was 0.05, so there is a 5% probability that observed differences in the means are due to chance.

To determine whether differences in the mean water levels in the pre- and post-restoration periods could have been due to differences in precipitation, a further analysis was conducted that tested for a change in the mean of the differences in water levels between each of the wells and a control well. Well 13 was selected as the control well because it showed the least difference in mean water levels between the pre- and post-restoration periods (see section 4.2.3).

Contour maps were developed to compare the direction of groundwater flow and the depth to the water table in the pre-restoration and post-restoration monitoring periods. The Surfer[®] contouring software package from Golden Software Inc. was used to develop the maps. Surfer[®] uses a universal krigging algorithm to estimate the spatial variations in a parameter such as water table elevations based on a set of discrete point measurements. Values are first estimated for points located on a grid, and these are then used to calculate the contours. Water table maps were generated based on the measured water table elevations in each of the fourteen wells and the two staff gages. Maps showing the mean depth to the water table during the growing season were prepared by subtracting the gridded water table elevations from the surveyed ground surface elevations and creating a contour map of the residual values.

Depth-duration curves were constructed to compare the percentage of days during the growing season when the water table was at different depths in the pre-restoration and post-restoration periods. For the purposes of this study the growing season at the study site was defined as 1 March - 31 October. This growing season was based on: i) the date of the first and last days with mean daily minimum temperatures less than 32°F at the Wilmington 7 climate station; ii) growing season dates as defined in Soil Survey of Pender County, North Carolina; and iii) consultation with local experts on the germination and establishment requirements of native savanna plant species.

4.0 RESULTS

4.1 PRECIPITATION

In 1997 the annual precipitation and precipitation during the growing season (as defined for this study) at the Wilmington 7 climate station were 89% and 76% of average, respectively (Table 1). While most of the monthly totals were close to average, the rainfall in August was the lowest on record at the Wilmington 7 climate station. Due to the moderating influence of a strong El Nino event, there were relatively few tropical storms in 1997, and none reached North Carolina (Gray et al., 1997).

Table 1. Monthly, annual and growing season precipitation totals in inches at Wilmington 7 climate station in 1997, 1998, 1999 and 2000, and mean values for the period 1948-2000. Bold text indicates maximum values and italicized text indicate minimum values for the period of record.

	1997	1998	1999	2000	Mean	SD
January	4.4	7.4	6.7	6.4	4.2	1.9
February	4.6	11.2	1.6	1.1	3.8	2.1
March	3.1	3.0	3.5	3.0	4.4	1.8
April	3.3	2.8	3.5	4.6	3.1	2.0
May	1.3	12.6	8.2	2.9	4.5	2.4
June	5.7	4.2	7.0	7.9	5.1	2.8
July	7.5	3.9	5.8	7.8	8.5	3.5
August	0.9	18.0	11.6	8.5	7.3	3.9
September	8.3	6.4	25.0	10.0	5.8	4.2
October	2.0	2.1	4.8	0.4	3.3	2.1
November	5.3	1.4	3.5	2.6	3.1	1.8
December	4.7	4.2	1.6	1.3	3.7	1.9
Growing season	32.0	52.9	69.3	45.1	42.0	
Calendar year	51.0	77.2	82.7	56.5	57.1	7.5

In contrast with 1997, 1998 was a very wet year and included some exceptionally large storm events. The annual precipitation total was the largest in the 48 year record at the Wilmington 7 climate station, and the growing season total was 126% of the mean (Table 1). The precipitation in February was the largest in the 48 year record, and included one 24-hour period with 4.8 inches of rainfall. Precipitation in May was also the largest on record, and included four days with more than an inch of rain. The total for August equaled the previous monthly maximum set in 1981. Approximately 80% of the August

precipitation was recorded on 27 August after Hurricane Bonnie made landfall on the North Carolina coast as a strong category 2 hurricane (Gray et al., 1998).

In 1999 precipitation was again well above average, and included one extreme storm event. The annual precipitation total exceeded the previous record set in 1998, and the growing season total was 165% of average (Table 1). The total precipitation in September (25.0 inches) far exceeded the previous record of 20.0 inches set in 1984. Over 77% of the total in September occurred in one 48-hour period after Hurricane Floyd made landfall near Cape Fear, North Carolina in the early morning hours of 16 September 1999. Hurricane Floyd was a strong category 2 hurricane when it reached the U.S. coastline. The storm produced exceptionally large amounts of precipitation, resulting in extensive flooding in the eastern U.S., particularly in North Carolina (Gray et al., 1999).

After two years with exceptionally high precipitation, 2000 was very close to the long term average. The annual precipitation total and the growing season precipitation total were 99% and 107% of average respectively (Table 1). Although the Atlantic hurricane season in 2000 was very active, only Hurricane Gordon made landfall in the U.S. (Gray et al., 2000). September was the wettest month in 2000; the monthly total included three days with over 1.5 inches of rainfall, two of which were associated with the same tropical storm system that spawned Hurricane Gordon.

4.2 SURFACE WATER AND GROUNDWATER HYDROLOGY

Seasonal and interannual differences in the elevation of the water table surface and the direction of groundwater flow at the study site reflected variability in the effect of the ditch and in the relative amounts of precipitation and evapotranspiration. Figure 4 shows water level data for the two staff gages S1 and S2. Water table maps for various dates during 1997, 1998, 1999 and 2000 are shown in Figure 5, 6, 7 and 8, respectively. Water table hydrographs for all fourteen wells are shown in Appendix 1, while data from wells 5, 6, 11 and 12 are described here to illustrate the overall trends (Figures 9a through 9d). Well 5 represents the conditions in the lower part of the meadow (wells 1, 2, 4 and 5).

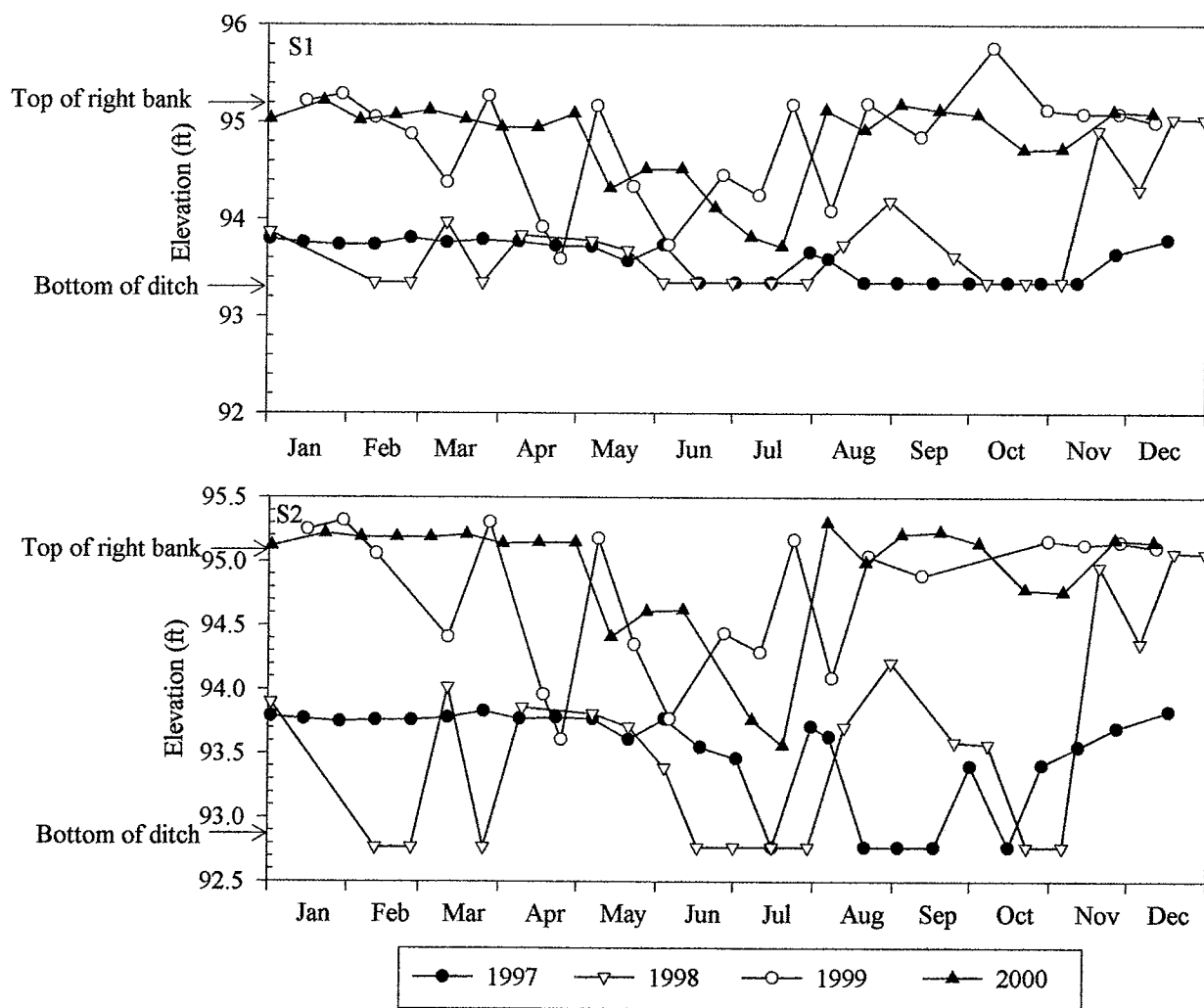


Figure 4. Stage at staff gages S1 and S2 in 1997, 1998, 1999 and 2000. All elevations are relative to a local datum.

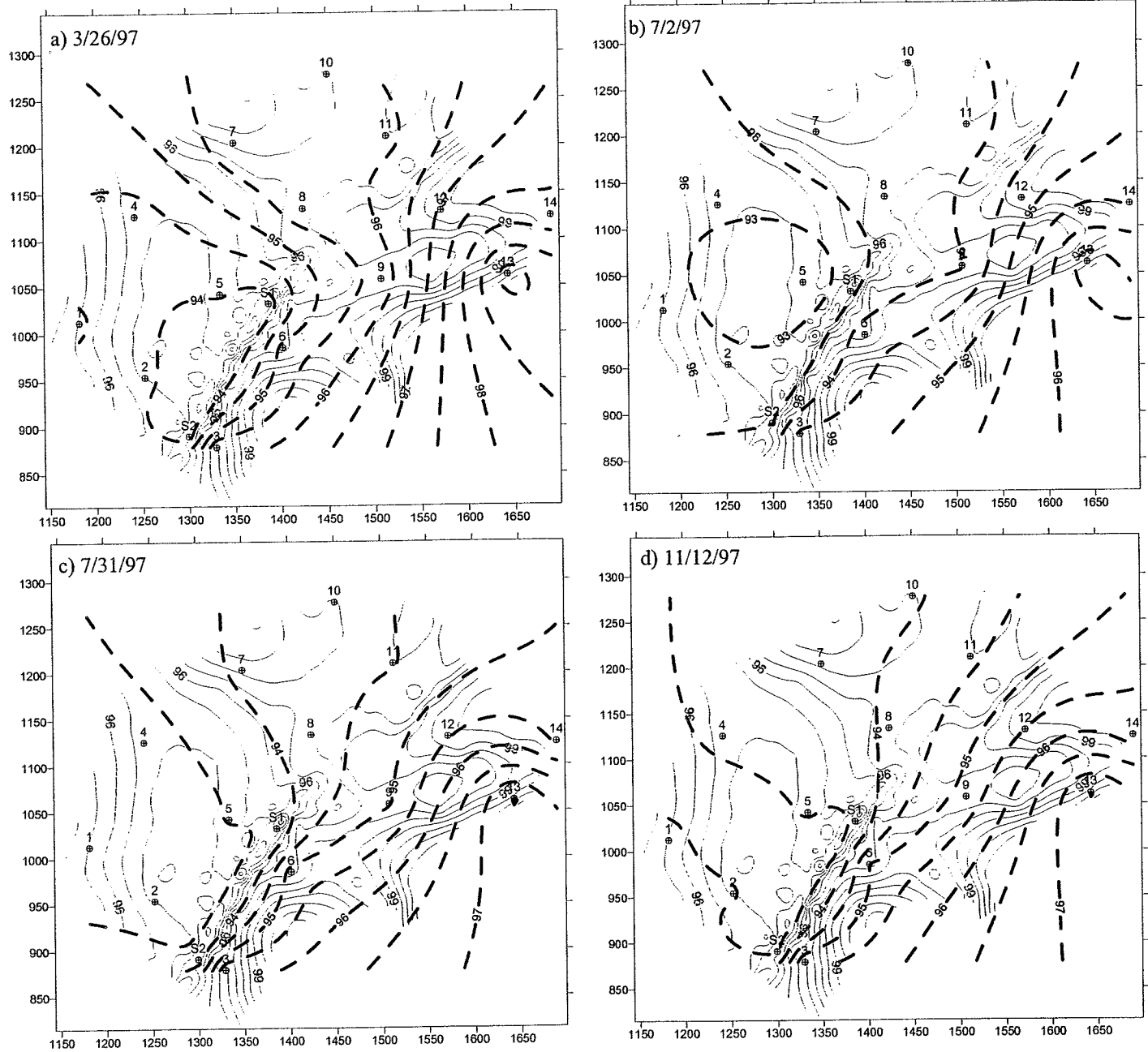


Figure 5. Water table surface elevations on a) 26 March, b) 2 July c) 31 July and d) 12 November 1997. Elevations are in feet relative to a local datum.

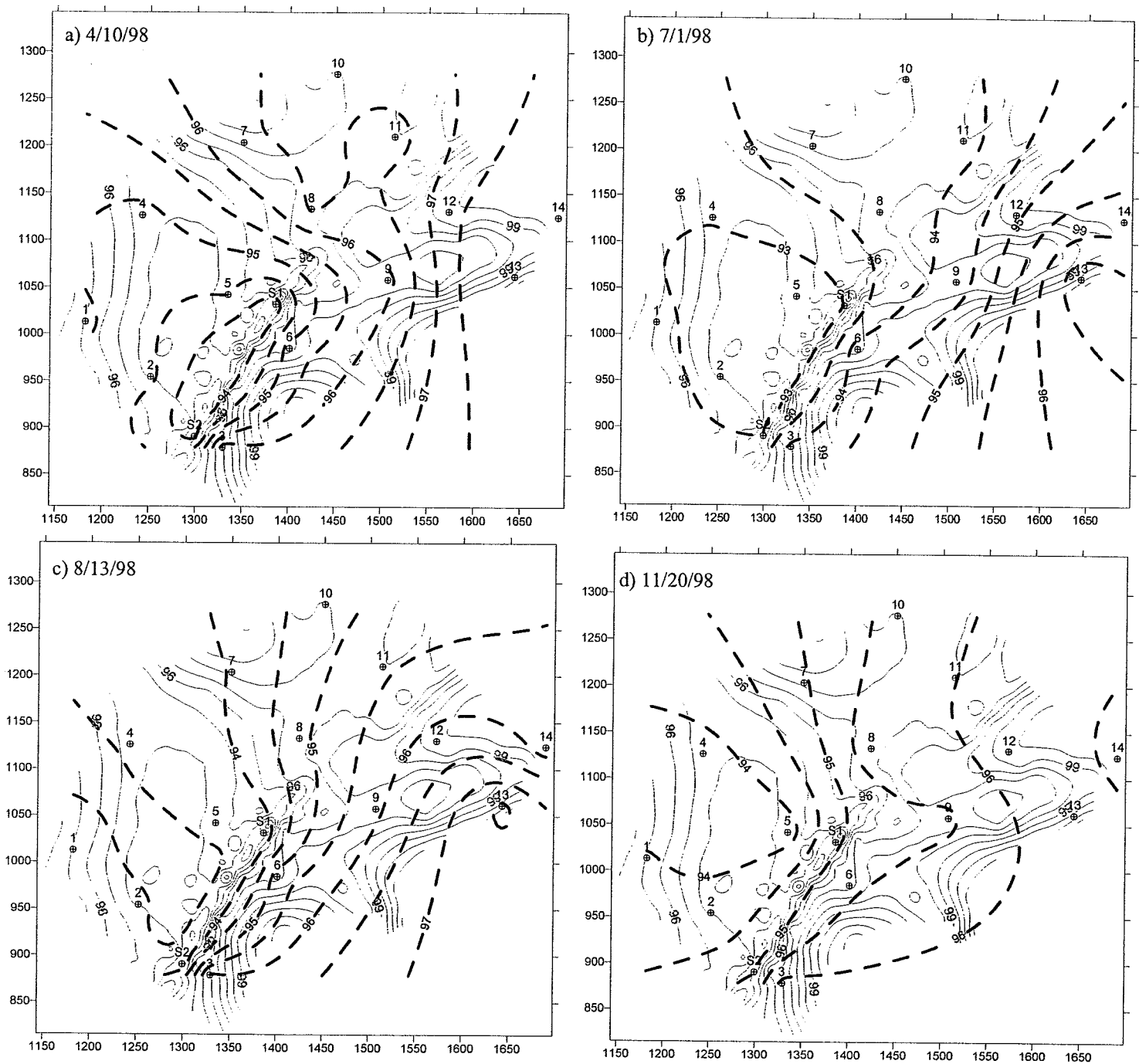


Figure 6. Water table surface elevations on a) 10 April, b) 1 July c) 13 August and d) 20 November 1998. Elevations are in feet relative to a local datum.

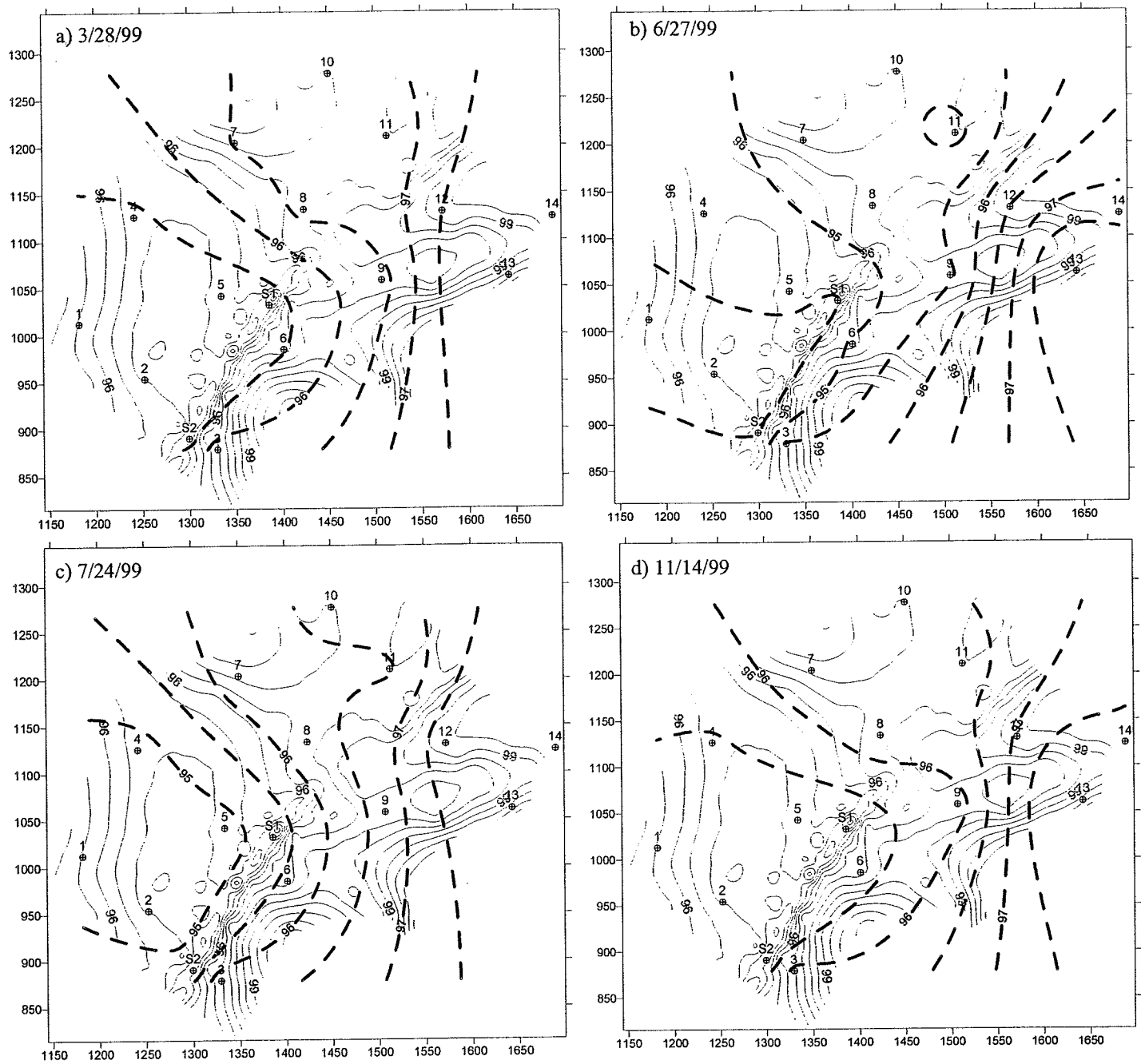


Figure 7. Water table surface elevations on a) 28 March, b) 27 June c) 24 July and d) 14 November 1999. Elevations are in feet relative to a local datum.

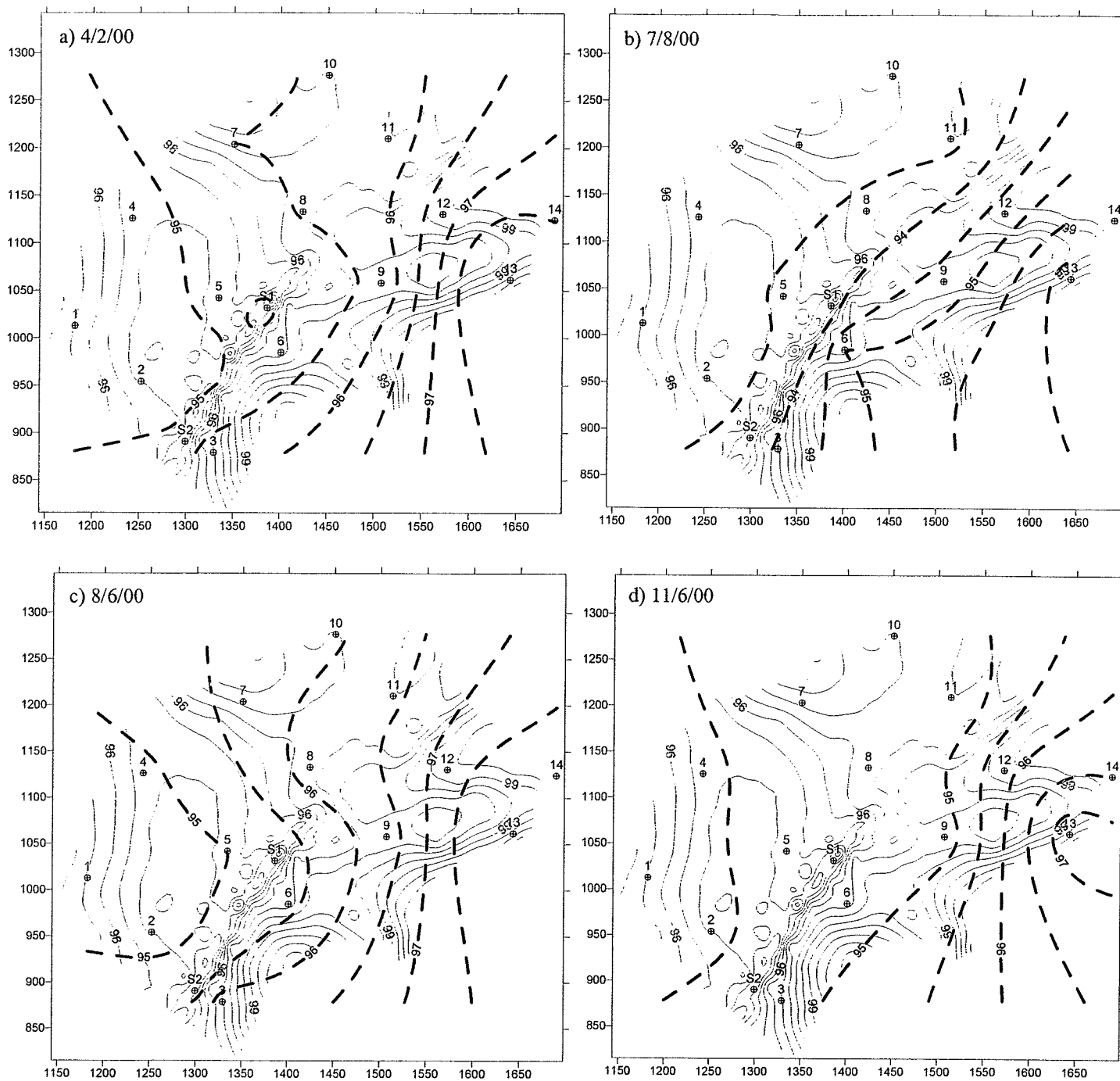


Figure 8. Water table surface elevations on a) 2 April, b) 8 July c) 6 August and d) 6 November 2000. Elevations are in feet relative to a local datum.

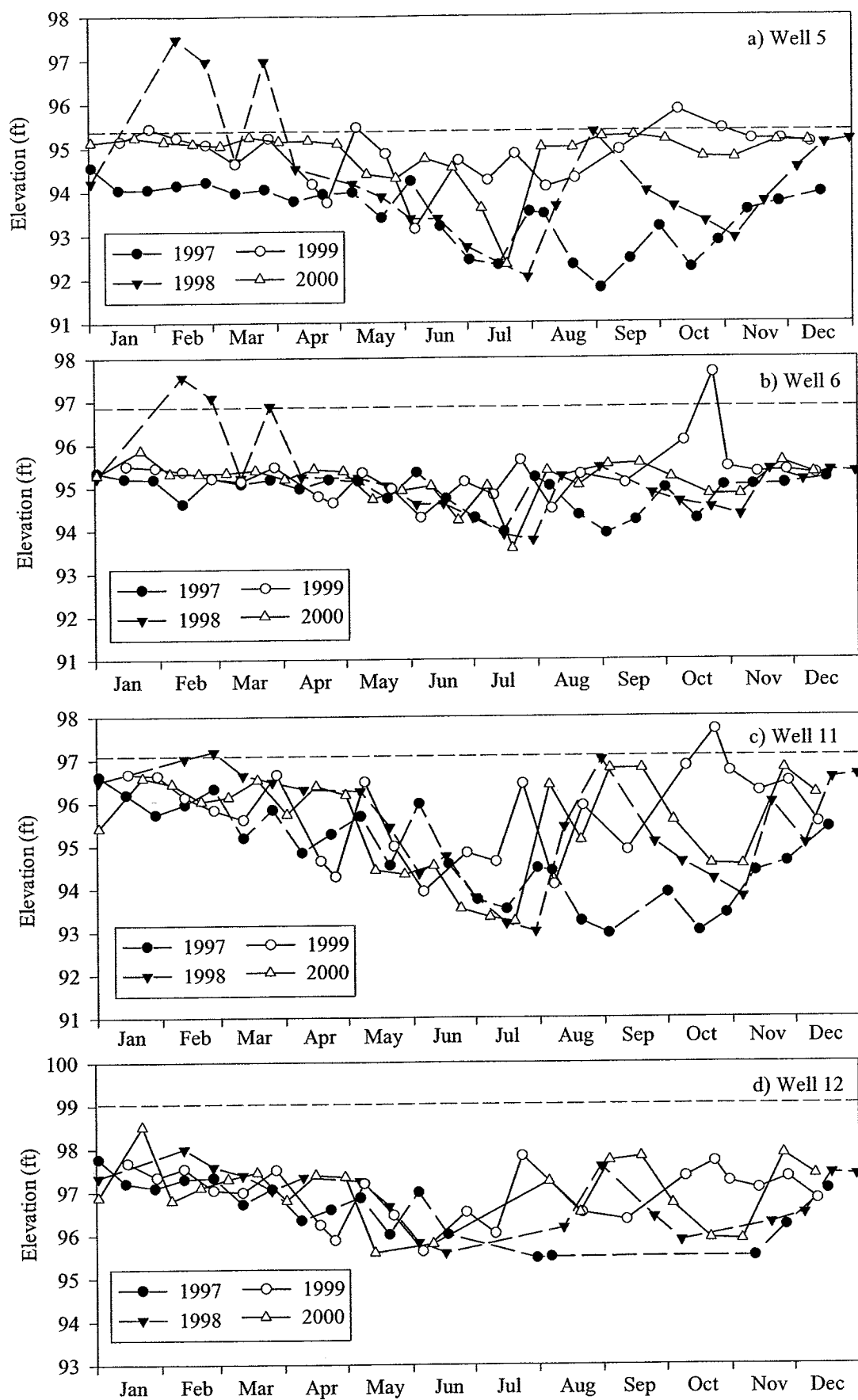


Figure 9. Water table hydrographs for wells a) 5, b) 6, c) 11 and d) 12 in 1997, 1998, 1999 and 2000. Dashed lines indicate ground surface elevations. All elevations are relative to a local datum.

Well 6 represents the conditions on the hillslope between the ditch and the visitor center (wells 3 and 6). Well 11 represents the conditions in the upper meadow (wells 7, 8, 10 and 11) and well 12 represents the conditions on the adjacent hillslope (wells 9, 12, 13 and 14).

4.2.1 Site hydrologic regime during pre-restoration phase.

In 1997 the maximum depth of water in the ditch was approximately 0.5 feet at staff gage S1 and approximately 1 foot at staff gage S2 (Figure 4). There were several periods during the summer when there was no water at either of the two staff gages. The highest water levels in the ditch during the pre-restoration period occurred in February 1998 following a series of large storms. The water levels for February 1998 shown in Figure 4 are estimates because the staff gages were inaccessible. From March until late August water levels were similar to 1997. Higher water levels in the ditch in late August and early September 1998 were caused by the rainfall associated with Hurricane Bonnie.

In 1997 the highest water table levels were measured in January, February and March. Water table levels in the upper and lower meadow areas were within 2 feet of the surface (Figures 9a and 9c), while water table levels on the hillslope were 1 to 3 feet below the surface (Figures 9b and 9d). There was groundwater discharge into the ditch from both the hillslope to the east and the meadow to the west. This is indicated by the convergence of the water table contours around the ditch in Figure 5a, which shows the conditions on 26 March 1997. While some groundwater from the hillslope flowed around the north end of the ditch and into the meadow, the ditch intercepted the groundwater discharging from a 250 feet wide section of hillslope. Presumably this lowered the water table level in the meadow.

Water table levels in all of the wells declined steadily between late March and mid-July 1997. Water table levels in the meadow dropped by up to 2.5 feet (Figures 9a and 9c), while water levels on the hillslope generally dropped by less than 2 feet (Figures 9b and 9d). This decline was most likely due to a progressive increase in evapotranspiration losses driven by increased solar radiation fluxes. Groundwater discharge into the ditch

ceased in early July after the adjacent water table level dropped below the bottom of the ditch. This is illustrated by the water table map for 2 July 1997, which shows groundwater flowing beneath the ditch instead of discharging into it (Figure 5b).

An increase in the amount of rainfall in late July 1997 resulted in an increase in water table levels, and in the amount of groundwater discharging from the hillslope towards the meadow. The water table level in most wells rose by approximately 1 foot. However well 12, which had gone dry in July remained dry (Figure 9d). As the water table rose it intersected the ditch, and groundwater once again began discharging into the ditch. This is illustrated by the closely spaced water table contours on the south side of the ditch in the water table map for 31 July 1997 (Figure 5c).

Water levels dropped again in August in response to the exceptionally low precipitation. Water levels measured during this period were some of the lowest measured at any time during the study. However, as evapotranspiration losses declined in the last part of 1997 the water table level gradually rose until it once again intersected the ditch. Consequently the conditions in November were very similar to those in July, with the ditch intercepting a portion of the groundwater discharging along the base of the hillslope (Figure 5d).

In 1998 the late winter and early spring were exceptionally wet and this caused water table levels to be higher than in 1997. Several exceptionally large storms in February resulted in flooding of the lower meadow. At well 5, for example, the water level on 12 February was almost two feet above the ground surface (Figure 9a). There was also standing water at well 6 (Figure 9b) and the ditch was completely under water. By April however, water table levels in most of the wells had dropped, and were similar to the water levels measured during the same period in 1997. The ditch water level was approximately 0.7 feet lower than the water table level in the meadow, and approximately 1.4 feet lower than the water table level at the foot of the hillslope, so there was groundwater discharge into the ditch from both sides (Figure 6a). The decline in water

levels continued until the end of July, and as in the previous year the water table eventually dropped below the bottom of the ditch (Figure 6b).

Groundwater levels increased in August 1998 due to the increased amount of rainfall, and the water table intersected the ditch again. The water table map for 13 August 1998 (Figure 6c) is therefore almost identical to that for 31 July 1997 (Figure 5c) and shows hillslope groundwater discharging into the ditch. The arrival of Hurricane Bonnie on 27 August resulted in an unprecedented amount of rainfall (14.4 inches in 24 hours at Wilmington 7) and this resulted in temporary flooding of the site. The water table hydrographs in Appendix 2 and Figure 9 do not fully represent the peak water levels because no data were collected until 4 days after the storm. However, most of the surface water rapidly drained from the site via the ditch, so that all of the wells except 2 and 4 had water levels below the surface by 31 August (Figure 9a through 9d). Groundwater discharge into the ditch continued through the late summer and fall of 1998 as water table levels remained high and the ditch water level remained low.

4.2.2 Site hydrologic regime during post-restoration phase.

After the drainage ditch was plugged in November 1998 there was an immediate rise in the water level at both of the staff gages. Water levels in the ditch during most of the post-restoration period were more than a foot higher than during the pre-restoration period, and were at or near the bankfull height for long periods (Figure 4). While the water in the ditch periodically dropped to levels similar to those measured in the pre-restoration period, the ditch never went dry. Water surface elevations at S1 and S2 were again almost equal, indicating that there was no flow along the ditch towards the outlet. The rise in the water level in the ditch had a substantial effect on groundwater flow in the vicinity of the ditch in November and December 1998. Instead of discharging into the ditch, groundwater from the hillslope was able to flow through the ditch and into the meadow (Figure 6d). This resulted in a further rise in the water table level that had already begun to rise because of a decrease in evapotranspiration losses in the early winter.

In the early part of 1999 water table levels were not as high as in the same period of 1998 due to the absence of large storms. However water levels in the meadow were much higher than in 1997, which had a similar amount of rainfall in the early part of the year. In well 5, for example the water table in mid-February 1999 was over a foot higher than in 1997 (Figure 9a). The increase in the water table level in the meadow was due primarily to increased recharge from the hillslope. Hillslope water table levels were also slightly higher than in 1997 (Figures 9b and 9d). Instead of draining out of the meadow along the ditch, groundwater flow along the base of the hillslope together with surface water runoff raised the water level in the ditch to the top of the bank. Water from the ditch then began recharging the water table in the meadow by a combination of groundwater and surface water flow. In effect, groundwater from the hillslope flowed through the ditch and into the meadow, and this is illustrated in Figure 7a.

Although water table levels in the meadow and on the hillslope declined during the summer of 1999, they were still higher than in the same period of 1997 and 1998. The lowest water levels occurred in early June, following several weeks of low rainfall. Although the monthly rainfall total for May was almost twice the mean, 80% of the rain fell in the first two days of the month and the rest of the month was quite dry. While water levels had declined in June, July and August of 1997 and 1998, they remained static or increased during the same period of 1999 (Figure 9). This may have been due in part to higher than average rainfall, but the accumulation of standing water in the ditch also played a role. This is evident from the fact that the wells with the biggest difference between 1999 water levels and the water levels in 1997 and 1998 were those closest to the ditch. For example, water levels in well 5 were more than 2 feet higher in June and July 1999 compared to the previous two years (Figure 9c). There was a weak gradient towards the ditch at its upper end, but along most of its length the ditch was recharging groundwater in the meadow (Figure 7b).

The extreme rainfall produced by Hurricane Floyd caused flooding of the study site between mid-September and early October 1999. Since the ditch had been plugged the surface water in the meadow could not drain as efficiently as it did during the storms of

early 1998, so flooding continued for several weeks. The well hydrographs shown in Figure 9 do not show the highest water levels associated with the effects of Hurricane Floyd because flooding prevented data collection until 10 October. Based on park staff accounts there was 2 to 3 feet of standing water in the meadow during this period. A secondary water level peak occurred in mid-October 1999 after almost 2 inches of rain fell on two consecutive days. Over a week after these storms, on 24 October 1999, water levels at the wells in the meadow were still between 0.4 ft and 1.1 ft above the ground surface (Figures 9a and 9c).

After the extreme precipitation events of September and October, November and December were not as wet and water levels in most wells either declined slightly or remained static in the latter part of 1999. By the end of the year most wells had water table levels that were similar to 1998. Due to the high water level in the ditch, hillslope groundwater continued to recharge the meadow area (Figure 7d).

Water levels in the study site in the first three months of 2000 were very similar to the first three months of 1999, reflecting the similarity between the precipitation totals in these two time periods (Table 1). The stability of the water level in the ditch compared to the previous year suggests that the plug had become even more effective in preventing leakage out of the ditch, and this helped to maintain more stable water levels in the meadow compared with 1999 (Figure 9a). Water levels in the meadow remained almost static until the end of April. Figure 8a shows the water table surface on 2 April 2000, with water flowing through the ditch and into the lower meadow as in most of 1999.

Water tables declined slowly in May and June and more rapidly in early to mid July. Although July had higher than average precipitation, almost all of the rainfall occurred in the last week of the month. Since the rest of the month was very dry, and there was high evapotranspiration, water table levels dropped more sharply. Water levels in the ditch during this period were the lowest of the year, but were still higher than in 1997 or 1998. Since water table levels in early July were close to the bottom of the ditch, the ditch had little effect on groundwater flow (Figure 8b).

Water table levels increased sharply after several days of intense rainfall in late July and early August. Early August water levels were as high as those measured at the start of the year, and were similar to the water levels produced by Hurricane Bonnie in August 1998 (Figures 9a and 9c). Water levels in the ditch were also high (Figure 4) and water from the ditch recharged the lower meadow (Figure 8c).

Water table levels in the upper meadow declined by over 2 feet between mid September and early November (Figure 9c). This was apparently due to a decline in groundwater recharge from the adjacent hillslope, as indicated by the declining water level in well 12 (Figure 9d). Although water levels dropped slightly in the lower meadow the decline was much smaller than in the upper meadow, and this was apparently due to a smaller decline in hillslope inflows (Figure 9b). Since the water level in the ditch remained high, hillslope groundwater was still able to recharge the lower meadow (Figure 8d). In years prior to the restoration water levels in the lower meadow would have dropped to levels similar to those in the upper meadow.

4.2.3 Comparison of pre-restoration and post-restoration water table levels

Mean water table levels in the pre-restoration period ranged from -1.26 ft in well 3 to -2.69 ft in well 14. Mean water table levels in the post-restoration period ranged from -0.46 ft in well 2 to -2.24 ft in well 12 (negative values indicate a water level below the ground surface). In all of the wells the post-restoration mean water table level was higher than the pre-restoration mean, and the difference was significant ($p < 0.05$) in all of the wells except W13 (Table 2). The standard deviation of the mean water table levels was less in all of the wells in the post-restoration period. Taken in combination these results indicate that water table levels in the post restoration period were generally higher and more stable than in the pre-restoration period.

Table 2. Mean and standard deviation of water table levels in the pre-restoration and post-restoration monitoring periods. Water levels are in feet relative to the ground surface, with negative values indicating a water level below the surface. Pre-restoration values are based on 45 measurements and post-restoration values are based on 51 measurements. Standard deviations are shown in parentheses. Significant p values (<0.05) are shown in bold type. Asterisks indicate p-values obtained from a Wilcoxon signed rank test.

Well No.	Pre-restoration mean	Post-restoration mean	p-value
1	-2.56 (1.19)	-1.80 (0.84)	0.001
2	-1.28 (1.10)	-0.46 (0.62)	<0.001
3	-1.26 (0.96)	-0.87 (0.79)	0.037
4	-1.52 (1.18)	-0.69 (0.68)	<0.001
5	-1.61 (1.20)	-0.54 (0.65)	<0.001
6	-1.90 (0.75)	-1.66 (0.54)	0.007*
7	-2.39 (1.29)	-1.70 (1.04)	0.006
8	-1.96 (1.30)	-1.21 (1.06)	0.003
9	-2.00 (1.02)	-1.46 (0.80)	0.006
10	-2.18 (1.34)	-1.47 (1.06)	0.005
11	-2.08 (1.26)	-1.41 (1.07)	0.006
12	-2.69 (0.84)	-2.24 (0.78)	0.008
13	-1.62 (1.18)	-1.31 (1.04)	0.059*
14	-2.69 (1.14)	-2.01 (0.94)	0.002

In nine out of thirteen wells the mean of the difference in water levels between the well and a control well (well 13) was significantly less in the post-restoration period (Table 3). This indicates that the rise in water levels in these wells in the post-restoration period was not due to the greater amount of precipitation. Well 13 was used as the control well for these analyses because there was no significant difference in water levels between the pre-restoration and post-restoration periods. The four wells where the means were not significantly different (nos. 3, 6, 9 and 12) are all located along the hillslope on the southeast side of the site. Water level increases in these four wells in the post-restoration period were most likely due to the increase in precipitation.

Table 3. Mean of the difference in depth to water table between study site wells and a control well (well 13) in the pre-restoration and post-restoration monitoring periods. Pre-restoration values are based on 45 measurements and post-restoration values are based on 51 measurements. The p-values were obtained from separate variance t-tests.

Well No.	Pre-restoration	Post-restoration	p-value
1	0.937	0.487	0.004
2	-0.334	-0.854	0.001
3	-0.362	-0.440	0.538
4	-0.099	-0.623	<0.001
5	-0.012	-0.770	<0.001
6	0.281	0.352	0.674
7	0.768	0.394	0.003
8	0.338	-0.098	<0.001
9	0.377	0.152	0.062
10	0.565	0.158	0.002
11	0.461	0.097	0.003
12	1.070	0.931	0.244
14	1.071	0.702	0.001

Due to the overall increase in water levels, the total area of the site with a mean depth to the water table during the growing season of less than 1 foot was greater in both years of the post-restoration period than in the two-year pre-restoration period (Table 4 and Figures 10a through 10d). The total area with a mean depth to the water table during the growing season of less than 2 feet also increased. Since 1997 was relatively dry compared to either 1999 or 2000, some of the difference between 1997 and the two post-restoration years is likely due to the higher amount of precipitation. However, the area of mean water levels within 1 foot of the surface was higher in 2000 than in 1998 despite the fact that 1998 was much wetter and included one extreme storm event. This indicates that the increase in wetland area with water levels less than 1 foot and less than 2 feet from the surface in 1999 and 2000 was due primarily to the effect of plugging the drainage ditch.

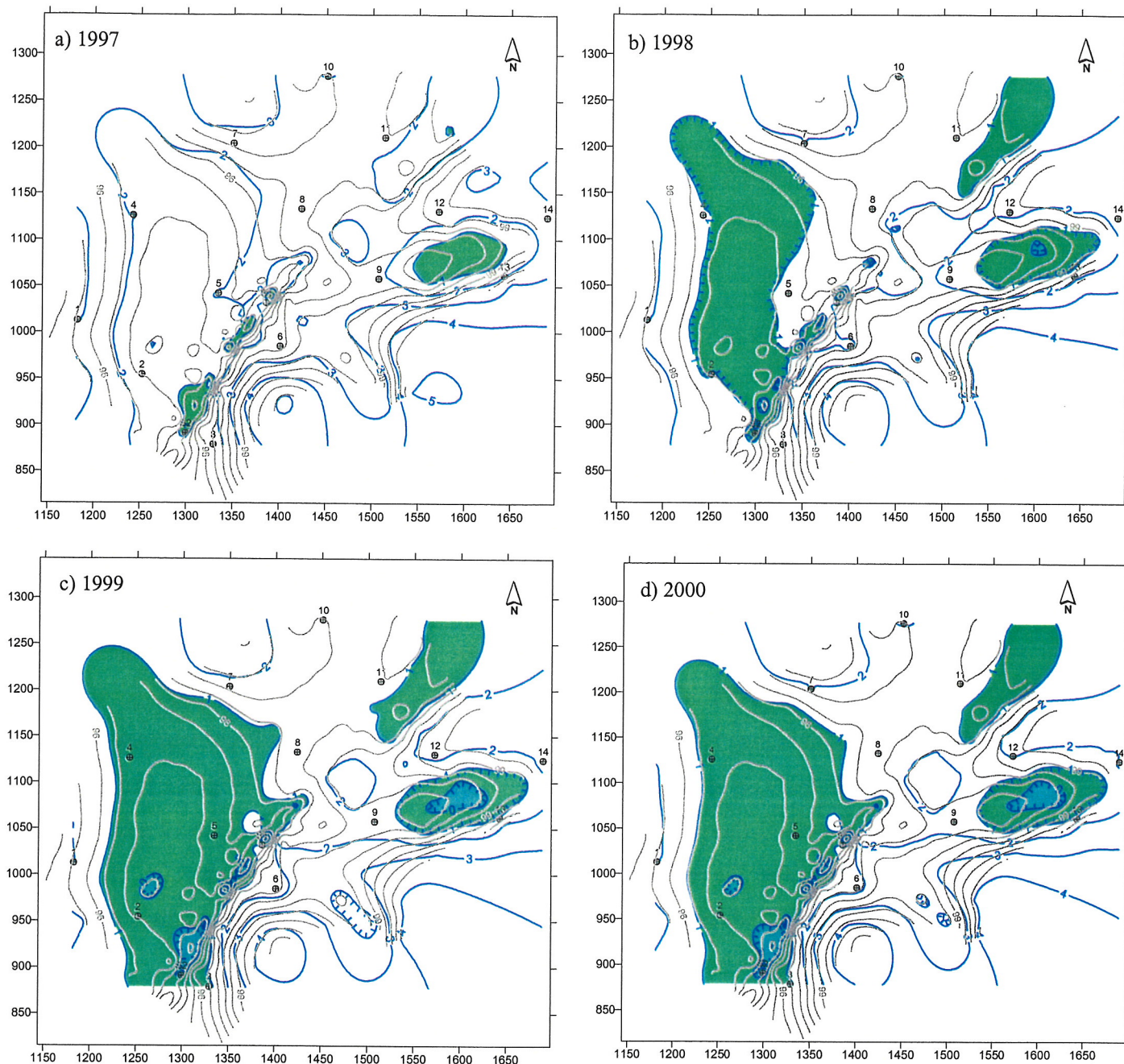


Figure 10. Mean depth to water table during growing season in a) 1997, b) 1998, c) 1999 and d) 2000. Blue lines are 1 foot contours of water table depth. Gray lines are 0.5 ft. topographic contours. Blue shading indicates areas with mean water table depth above ground surface. Green shaded areas indicate mean water table depth of 0-1 foot.

Table 4. Area in acres and percentage of total study area (in parentheses) where the mean water table level during the growing season was within 1 foot, between 1 feet and 2 feet, and greater than 2 feet from the ground surface in 1997, 1998, 1999 and 2000. Total study area is 4.6 acres and includes upland as well as wetland areas.

Year	< 1 ft	> 1ft and <2 ft	>2 ft
1997	0.14 (3.0)	1.28 (28)	3.22 (69)
1998	0.91 (20)	1.77 (38)	1.96 (42)
1999	1.48 (32)	1.56 (34)	1.60 (34)
2000	1.39 (30)	1.58 (34)	1.67 (36)

In twelve of the fourteen wells the percentage of growing season days when water levels were within 1 foot of the ground surface was greater in the post-restoration period than in the pre-restoration period. This is most clearly illustrated by the depth-duration frequency curves shown in Figures 11a through 11n. The biggest increases occurred in wells 2 and 5, which lie immediately to the northwest of the drainage ditch (Figures 11b and 11e). In well 5, for example, the percentage of growing season days when the water table was within 12 inches of the surface increased from less than 20 % in the pre-restoration period to almost 80% in the post-restoration period. The smallest increases were in wells 3, 6 and 9 on the hillslope on the southeast side of the ditch (Figures 11c, 11f, and 11i). In well 12 there were no days when the water level was less than 12 inches from the surface in either the pre-restoration or post-restoration periods (Figure 11l). In well 13 the percentage of days with a water level less than 12 inches from the surface was actually slightly less in the post-restoration period (Figure 11m).

4.2.4 Comparison of post-restoration hydrologic conditions with the reference site

The Green Swamp, located in Columbus and Brunswick counties southwest of the National Battlefield, is primarily an area of pocosin peatlands intermixed with pine savanna habitats on slightly higher mineral soil “islands.” Walker and Peet (1983) studied the species composition of pine savannas in the Green Swamp, and reported that the area contains some of the most extensive and best preserved pine savanna ecosystems on the Atlantic Coast. Therefore, this area provides potential “reference models” for the types of habitats that could be restored at Moores Creek.

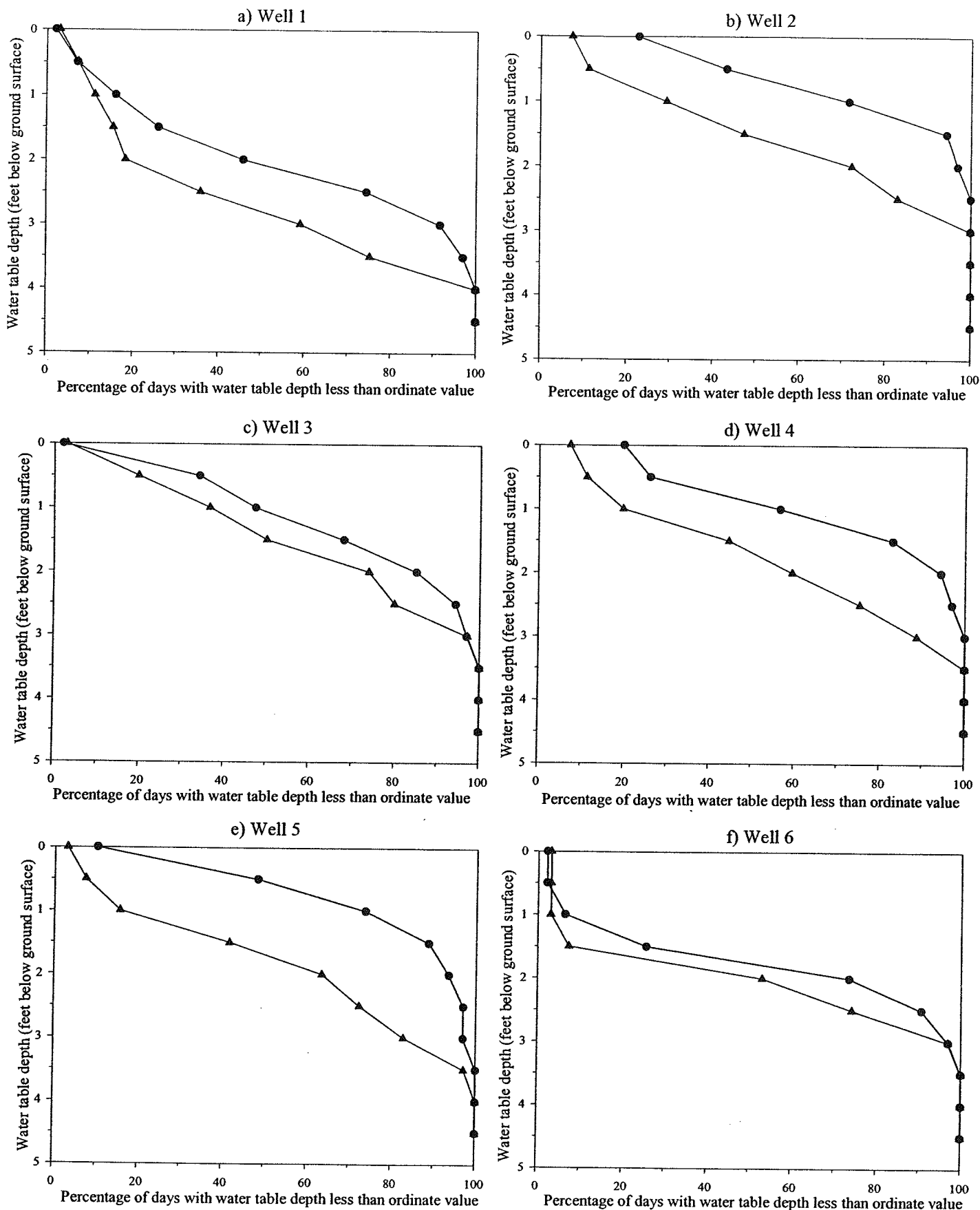


Figure 11. Depth-duration curves for pre-restoration (1997 and 1998) and post-restoration (1999 and 2000) growing season periods (1 March - 31 October) for wells 1- 14 at Moores Creek National Battlefield Park. Triangles represent pre-restoration period and circles represent post-restoration period.

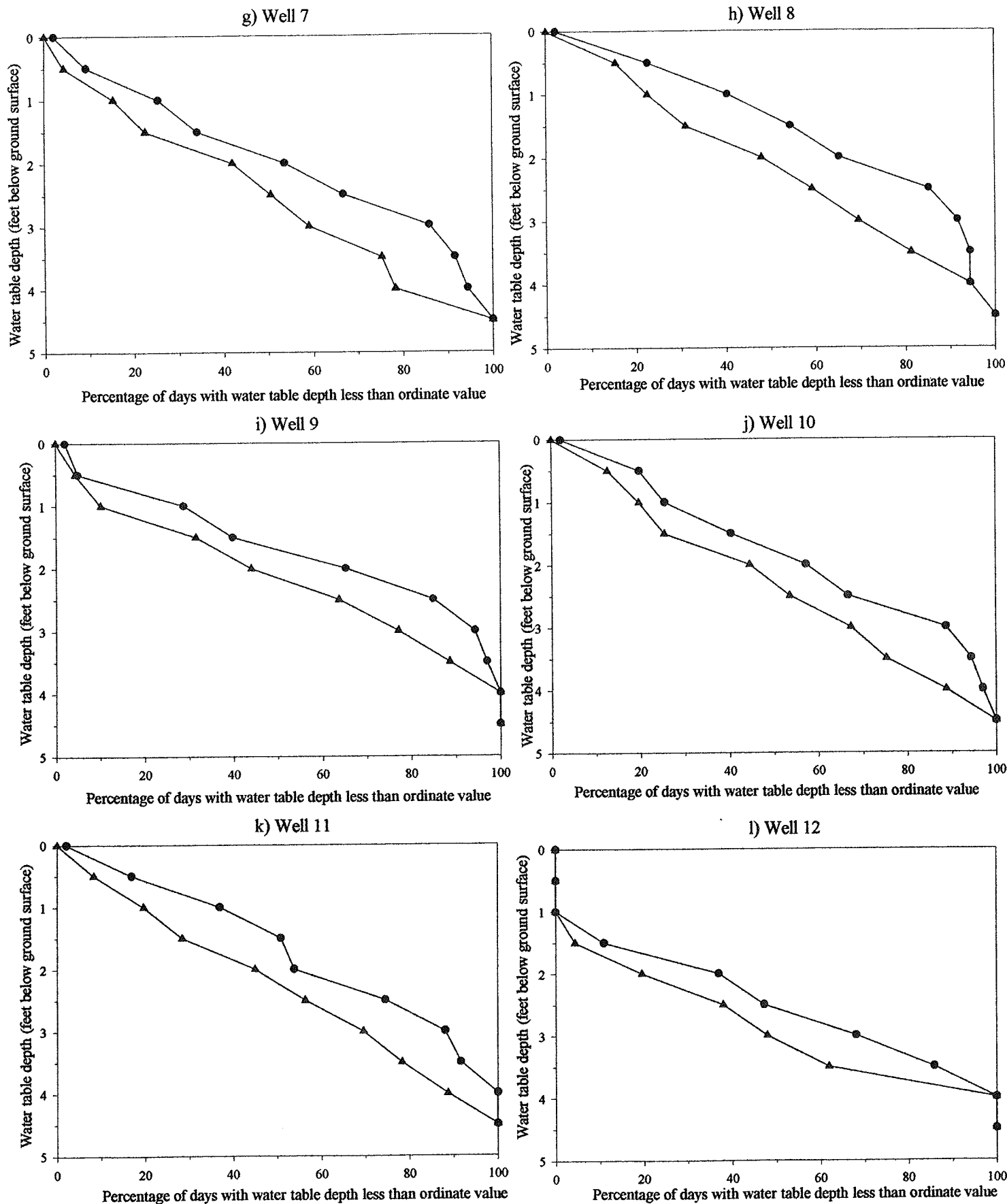


Figure 11 (cont'd). Depth-duration curves for pre-restoration (1997 and 1998) and post-restoration (1999 and 2000) growing season periods (1 March - 31 October) for wells 1- 14 at Moores Creek National Battlefield Park. Triangles represent pre-restoration period and circles represent post-restoration period.

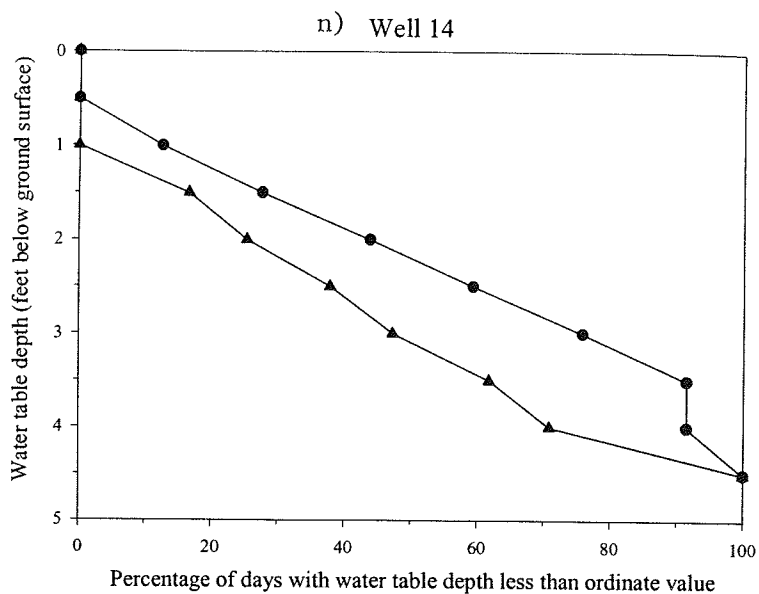
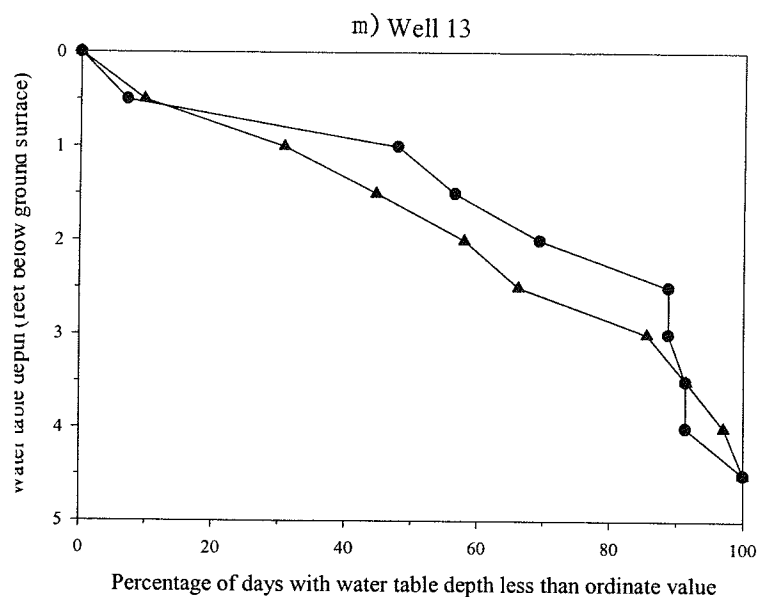


Figure 11 (cont'd). Depth-duration curves for pre-restoration (1997 and 1998) and post-restoration (1999 and 2000) growing season periods (1 March - 31 October) for wells 1- 14 at Moores Creek National Battlefield Park. Triangles represent pre-restoration period and circles represent post-restoration period.

Walker and Peet (1983) describe three types of pine savanna ecosystems in the Green Swamp: wet savannas, mesic savannas, and dry savannas. Although they did not collect hydrologic data to characterize each of these savanna types, they do describe their hydrologic properties and landscape positions.

“Wet savannas” are found in shallow depressions or as ecotones between the wetter, shrub-dominated pocosins and the somewhat drier “mesic savannas.” Dominant grasses include toothache grass (*Ctenium aromaticum*), savanna muhly (*Muhlenbergia expansa*), and Carolina dropseed (*Sporobolus teretifolius*). Shrub species include blueberry (*Vaccinium corymbosum*) and titi (*Cyrilla racemiflora*), and tree species include longleaf pine (*Pinus palustris*), pond pine (*Pinus serotina*), bald cypress (*Taxodium ascendens*), and black gum (*Nyssa sylvatica* var. *biflora*). Several pitcher plant species (*Sarracenia* spp.) and the sedge *Carex verrucosa* are also characteristic of wet savannas. Walker and Peet (1983) describe wet savannas as having “extended period(s) of winter and spring inundation.”

“Mesic savannas” occur in “an intermediate position on the (savanna) moisture gradient and are especially rich in (plant) species” (Walker and Peet, 1983). Where present, the tree canopy is almost exclusively longleaf pine. Important grass species include toothache grass, savanna muhly, Carolina dropseed and wiregrass (*Aristida stricta*). The diverse herbaceous plant community also commonly includes the endemic Venus’ flytrap (*Dionaea muscipula*) as well as club mosses, sedges, sundews, pitcher plants, and many species of composites. Walker and Peet (1983) state that the water table in these diverse mesic savannas is “within a few centimeters of the surface during spring and after heavy rains.”

“Dry savannas” occur on the higher portions of the savanna islands in the Green Swamp, up to about 1.5 meters above the surrounding pocosins. Wiregrass dominates the herbaceous plant community, and the tree canopy is restricted to longleaf pine. Although Walker and Peet (1983) do not characterize dry savanna water tables in any detail, we infer from their general descriptions and from data described below that water levels

probably remain more than a foot below the ground surface throughout the year, except during extreme events.

Shoestring Savanna, which is located in the Green Swamp 27 miles southwest of Moores Creek, is the only undisturbed pine savanna system in the region for which reference hydrologic data could be located. In the early 1990's, The Nature Conservancy monitored a transect of four wells representing the topographic and plant community variation across the savanna. During a site visit in February 2001 we were able to locate well 4, which is at the northeast end of the transect where the savanna grades into an adjacent pocosin. This well represents a wet savanna community that includes Venus' flytraps, toothache grass, and at least three species of pitcher plants (pers. comm., Linda Gintoli, The Nature Conservancy). We were also able to find well 3, which is in the middle of the transect and is in a dry savanna habitat approximately 1.5 meters higher than the wet savanna at well 4. This site is dominated by wiregrass in the herbaceous layer and longleaf pine in the canopy. We were not able to locate either well 1, which represents the ecotone between the savanna and the pocosin on the southwest end of the transect (probably wet savanna), or well 2 (probably mesic savanna), which is located between well 3 (dry savanna) and the wet savanna at well 1.

The data we were able to obtain from TNC were for June and July of 1990 and June through mid-September, 1992. Precipitation in June 1990 was only 0.3 inches (well below the 5.1 inch monthly average), and July was also below average. Neither of the two post-restoration years (1999-2000) had comparable rainfall conditions, so it was determined that comparisons of water levels between Shoestring Savanna in 1990 and the Moores Creek site in the post-restoration period were not appropriate. In 1992, the precipitation totals for June and August were above average, while July was below average. Precipitation in the summer of 1999 was very similar to the 1992 pattern, thereby allowing a comparison of water levels between the undisturbed Shoestring Savanna in 1992 and the restored Moores Creek site in 1999. (Hurricane Floyd caused overall 1999 precipitation to greatly exceed normal for the year, but it occurred after the comparisons discussed here.) A general comparison indicates that the water levels in the

Shoestring Savanna wells in June to mid-September 1992 (Figure 12) fluctuated in a manner similar to those at the Moores Creek site in June to mid-September 1999 (Appendix 1). Water levels in both sets of wells generally declined from June to mid-July, but increased again in late July and August.

During June to mid-September 1999, wells in the wetter portions of the Moores Creek site (wells 2, 4, and 5 in the lower meadow) had water levels similar to those from wells 1 and 4 (wet savanna) at Shoestring Savanna for the comparable period in 1992. Examination of the post-restoration hydrographs (Appendix 1) shows that these three Moores Creek locations are also consistent with Walker and Peet's (1983) description of wet savanna hydrology.

Six other Moores Creek wells (3, 8, 9, 10, 11, and 13) had water levels similar to well 2 at Shoestring Savanna (transitional between wet and dry savanna) during the two June to mid-September time periods. These six wells are located in the upper meadow and on hillslopes behind the park's visitor center. Examination of the full post-restoration hydrographs for Moores Creek (Appendix 1) shows that these six locations are also consistent with Walker and Peet's (1983) description of mesic savanna hydrology.

Well 12 at Moores Creek had water table characteristics similar to well 3 at Shoestring Savanna (dry savanna) during the two June to mid-September time periods. The water table was always deeper than 1 foot below the ground surface at both sites, and dropped to several feet below ground surface during drier periods. The full post-restoration hydrograph for well 12 at Moores Creek indicates that this pattern held very consistently over the 1999-2000 monitoring period.

Wells 1, 6, 7, and 14 at Moores Creek had water levels that appeared to fall somewhere between the mesic and dry savanna characteristics indicated by the Shoestring Savanna wells and the Walker and Peet (1983) descriptions. Wells 1, 6, and 7 represent areas that are on the higher margins of the upper and lower meadow, while well 14 appears to be

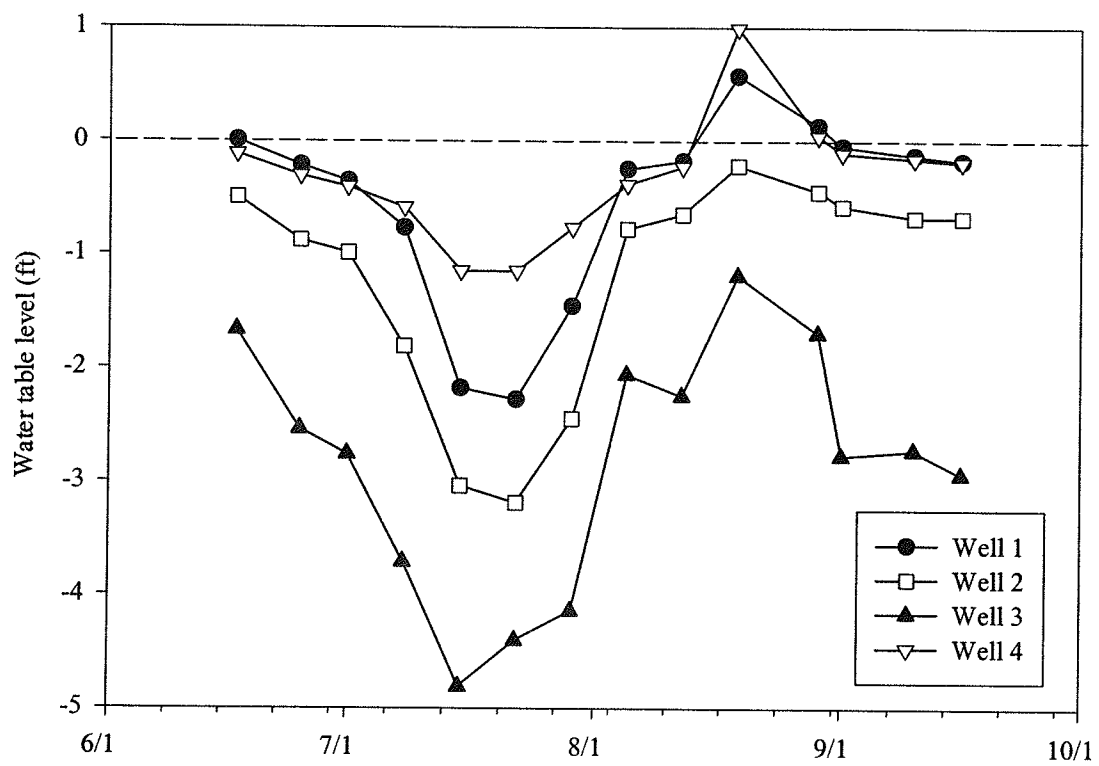


Figure 12. Water levels in feet in wells 1 - 4 at Shoestring Savanna, June - September 1992. Negative values indicate a water level below the surface.

transitional between the mesic slope behind the visitor center and the dry savanna habitat near well 12.

4.2.5 Areas of equivalent hydrology

One of the objectives of this report is to characterize the restored hydrology at Moores Creek in a way that would be useful in guiding subsequent restoration actions such as determining suitable locations for planting bunch grasses or other native species or for preparing a prescribed burn plan. After consulting with Brian van Eerden of the Nature Conservancy and other project cooperators, we decided this could be done by identifying “areas of equivalent hydrology.” Figure 13 shows a series of maps indicating ponded areas and areas where the water table was within a foot of the ground surface for six dates spanning the 2000 growing season (a near “normal” rainfall year as shown in Table 1). As an approximate guide, the seasonally ponded areas are potential wet savanna areas, the areas with the water table within a foot of the surface (but not ponded) represent more mesic savanna communities, and the areas where the water table is never within a foot of the surface should correspond to dry savanna habitat.

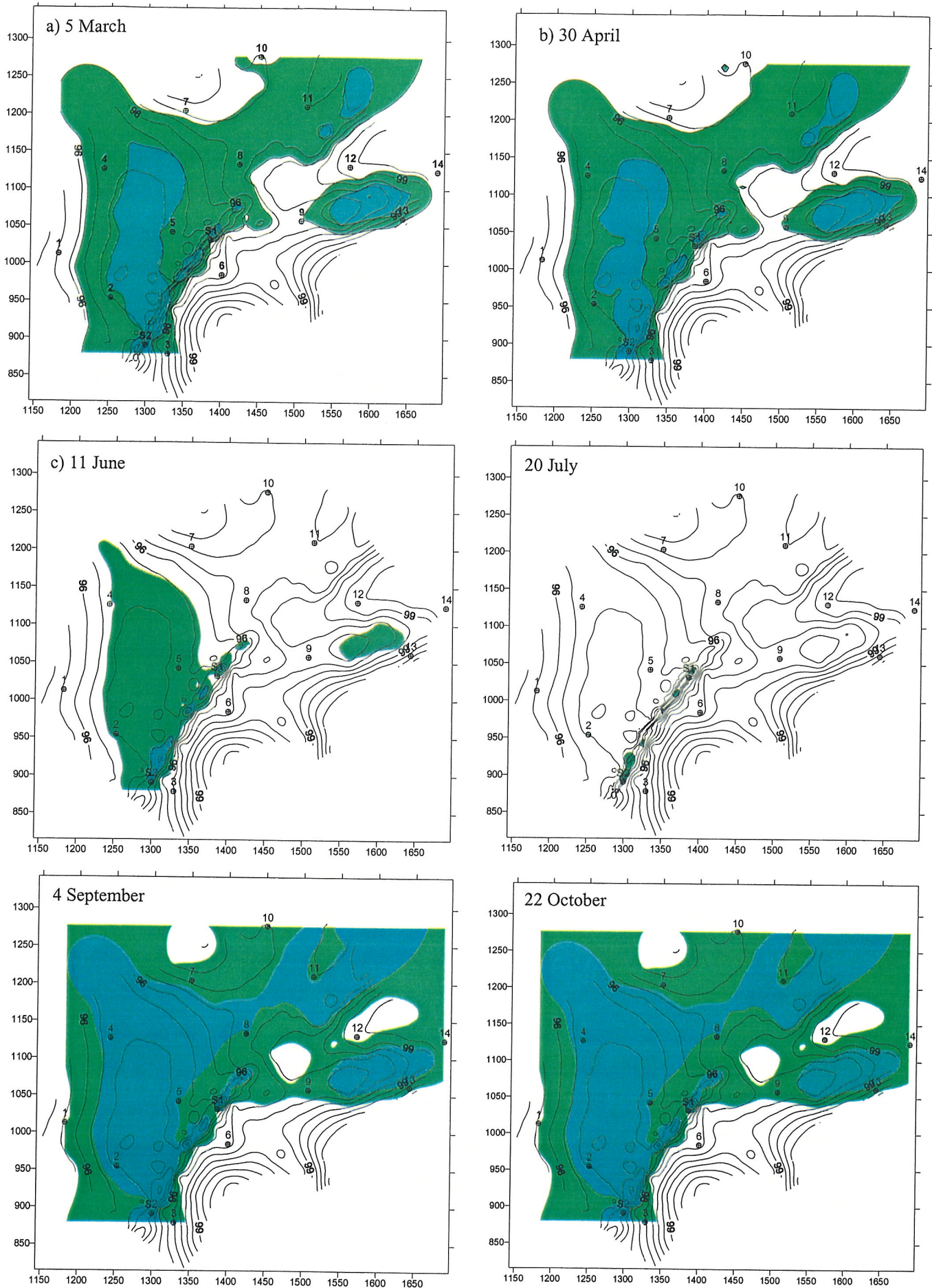


Figure 13. Estimated extent of area of flooding (blue shading) and area with water table within 1 ft of ground surface (green shading) on a) 5 March, b) 30 April, c) 11 June, d) 20 July e) 4 September, and f) 22 October 2000.

5.0 DISCUSSION AND CONCLUSIONS

Prior to the experimental restoration of the Moores Creek site, the drainage ditch lowered the water table in the meadow area by intercepting groundwater flow along a 250 feet wide section of hillslope. More water was lost to seepage into the ditch during periods when there was the greatest amount of groundwater flow from the hillslope towards the meadow. In drier periods the hydraulic gradient towards the ditch decreased, resulting in lower net groundwater inflows than in wet periods. In the driest parts of the year the water table dropped below the level of the ditch, and the ditch ceased to have any effect on wetland water levels.

The experimental restoration at the Moores Creek site has resulted in two major hydrologic changes. First, plugging the ditch has re-established the hydrologic connection between the hillslope below the visitor center and the lower part of the meadow. Seepage losses into the ditch have been reduced because of the higher water levels in the ditch. High water levels in the ditch are maintained by surface water runoff and groundwater inflows. The increase in the ditch water level also means that groundwater now flows out of the ditch and into the adjacent lower meadow for much of the year. The net effect is an increase in the amount of water reaching the lower meadow, and a statistically significant increase in wetland water levels.

Second, plugging the ditch has also reduced the rate of surface water runoff during large storms. Tropical storms are fairly common in this area, and they can produce exceptionally large rainfall events. Under the pre-restoration conditions surface water only accumulated briefly after large storms. The ditch provided a conduit for efficient drainage from the wetland, so surface water quickly dissipated. Under the present conditions surface water runoff is prevented by the plug in the ditch, so large storms cause extensive flooding in the wetland area that takes several weeks to dissipate. The net result is an increase in the amount of surface water that infiltrates to the water table, and a further increase in wetland water levels.

Comparison of post-restoration (June to mid-September 1999) Moores Creek well hydrographs with June to mid-September 1992 well data from an undisturbed reference site at Shoestring Savanna indicate that the water tables at the two sites fluctuated in a similar pattern in response to comparable precipitation. Most significantly, all 14 wells at Moores Creek fluctuated in the same depth to water ranges as the Shoestring Savanna wells representing a range of wet to dry savanna habitats. Examination of the full two years of post-restoration well records (1999 – 2000) from Moores Creek indicates that the restored site could support all three savanna types (wet, mesic, and dry) described by Walker and Peet (1983). More specifically, the majority of the upper and lower meadow areas could support wet to mesic savanna communities (given the appropriate fire regime), while mesic to dry savanna conditions may prevail on the margins of the meadow where depths to water are somewhat greater. The area in the vicinity of well 12 could be expected to support only a dry savanna community. The maps showing areas with similar depths to water (Figure 13) should aid in developing a planting plan for the four targeted bunchgrass species (toothache grass, savanna muhly, Carolina dropseed, and wiregrass) or other species that are critical to restoring the historic pine savanna habitats at Moores Creek National Battlefield.

The next step in the hydrologic restoration process is to decide whether or not to backfill the entire length of the ditch. The hydrologic benefits achieved by plugging the ditch would be made permanent by filling the ditch, and the original grade would also be restored. However, if the presence of rare species in the ditch makes this action undesirable, a similar effect could be achieved by reinforcing the existing plug. If the ditch is to be filled, great care must be used in selecting the fill material. If the material has too low a hydraulic conductivity the filled ditch will impede the flow of groundwater into the meadow, severely reducing the recharge to the meadow from the hillslope. Using material that is too coarse could create a conduit for subsurface drainage that would also limit flow into the meadow. The best procedure for filling the ditch would be to use a fill material as similar as possible to the soils in the wetland, and to insert sheet metal cut-off walls perpendicular to the axis of the ditch to limit the flow of groundwater along the filled ditch.

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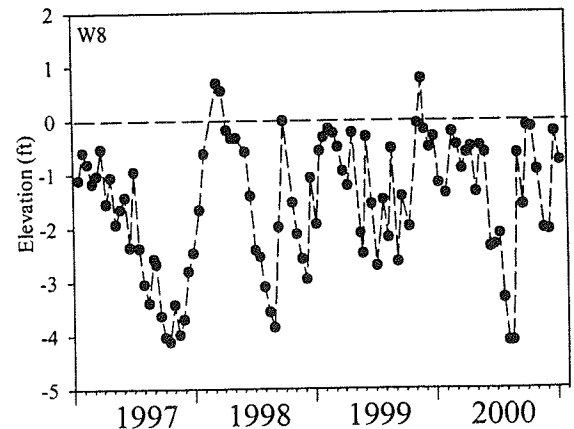
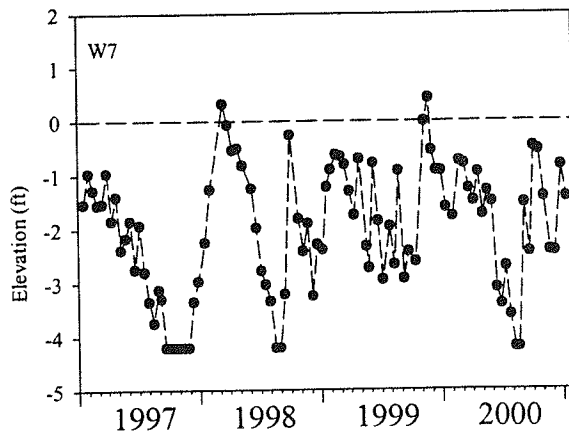
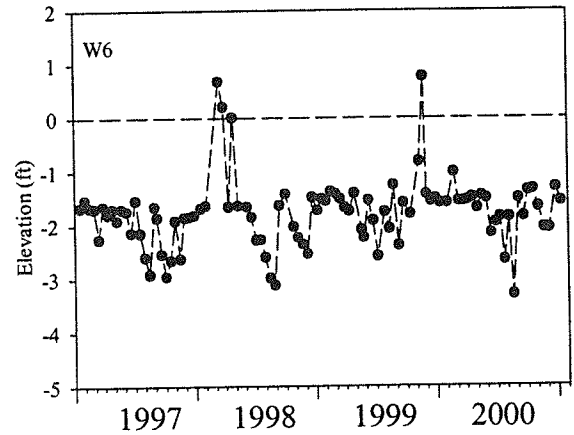
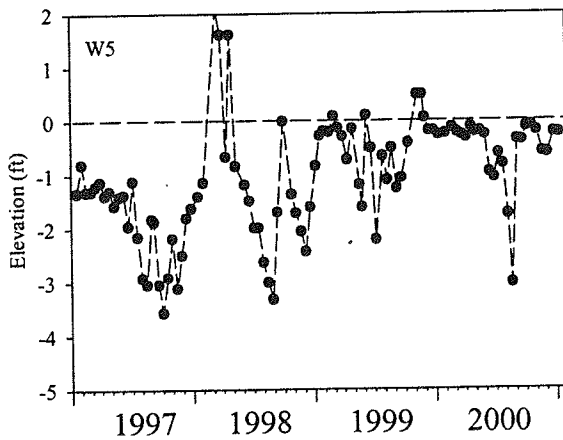
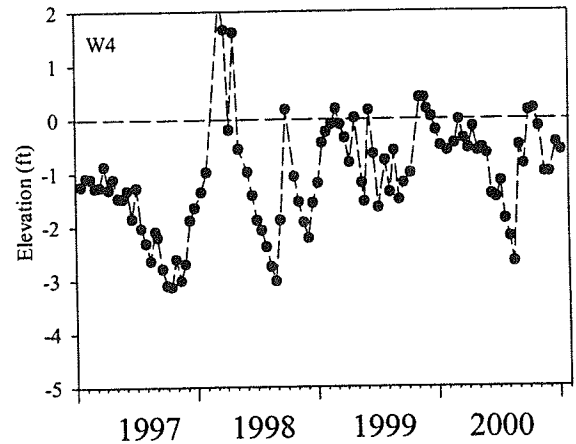
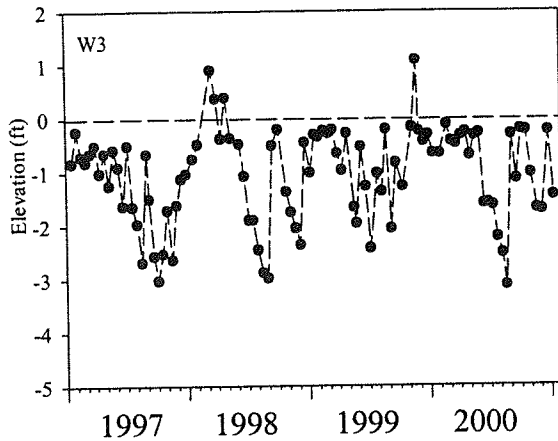
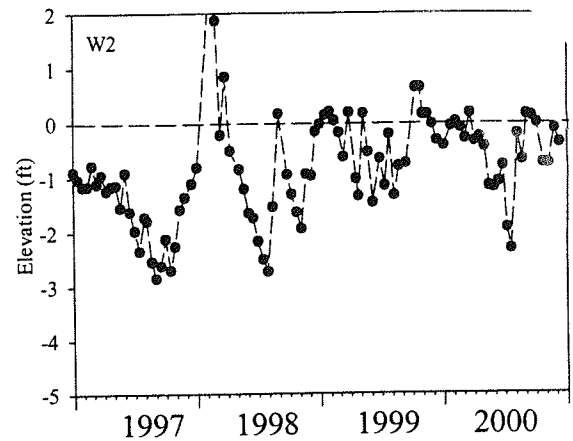
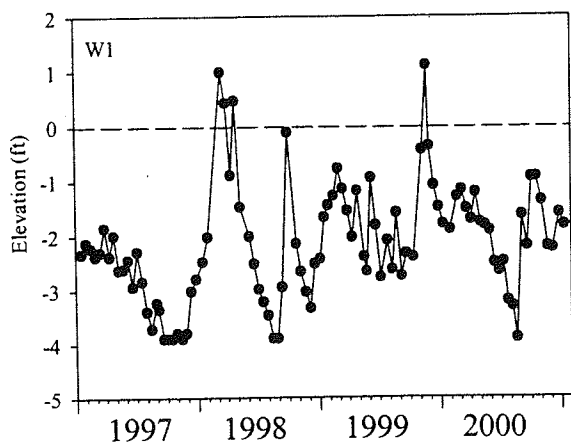
Lee Pelej (EPA Region IV) has provided valuable technical expertise in pine savanna fire and vegetation ecology, hydrology, and many other aspects of this restoration effort. Lee recognized the potential for restoring the site early on, and much of the project's success to date is a result of his participation. Richard LeBlond (North Carolina Heritage Program) has made many significant contributions to the project in the areas of rare plant protection, plant identification, and other aspects of savanna ecology. His vast knowledge and continuing assistance and advice are critical to the project's success. Mike Martin (NPS Water Resources Division) conducted all of the survey work needed to relate water table and ground surface elevations to a common datum. He created the topographic map for the site and prepared water table maps that we used to understand the pre-restoration period hydrology and to plan the restoration experiment. Mike's hard work, expertise, advice, and enthusiasm are greatly appreciated.

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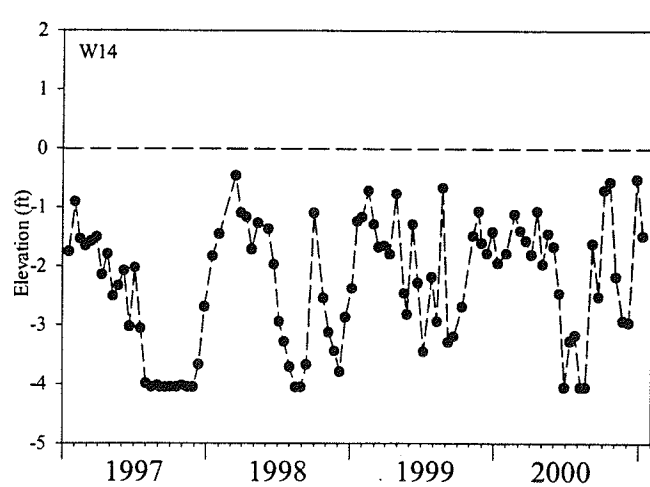
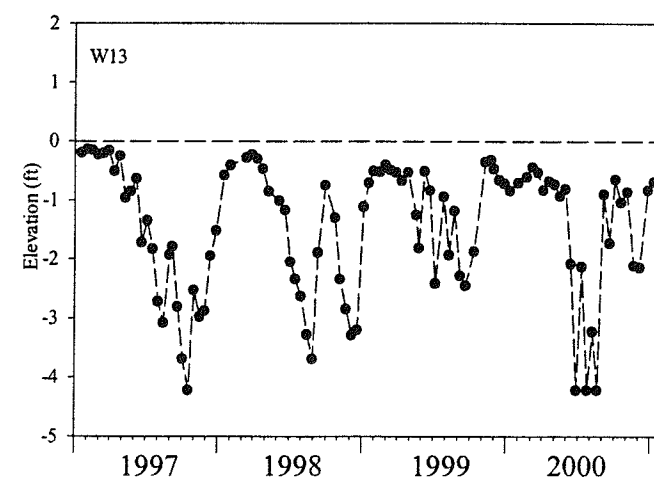
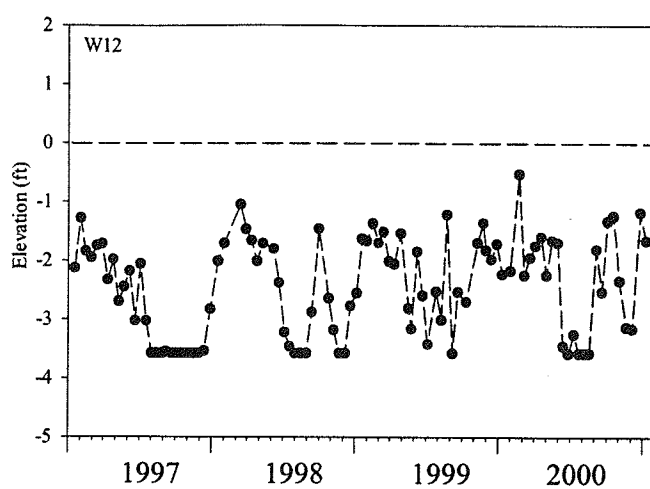
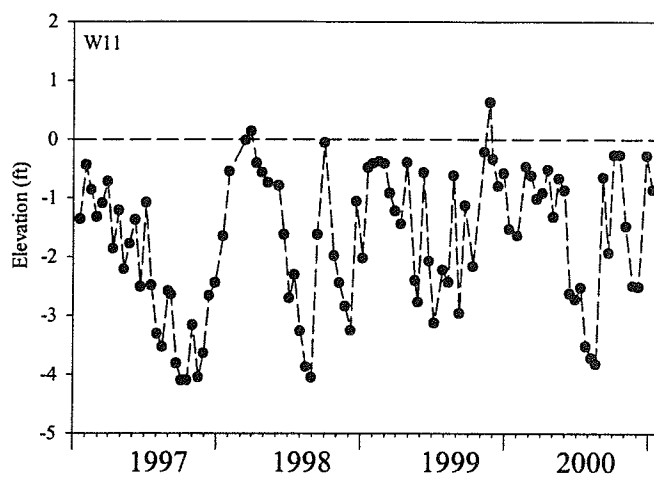
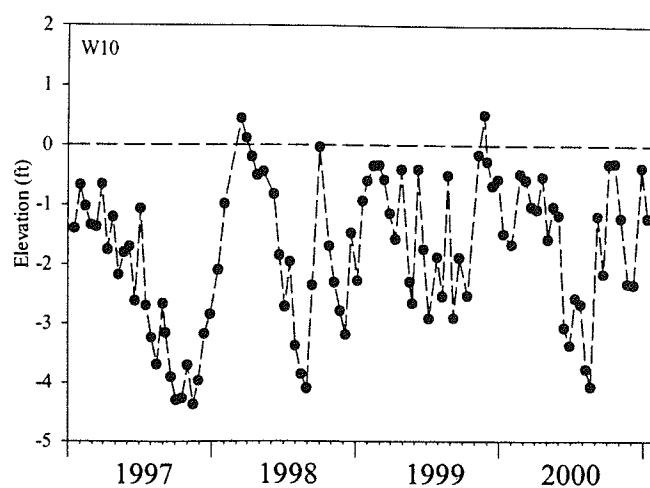
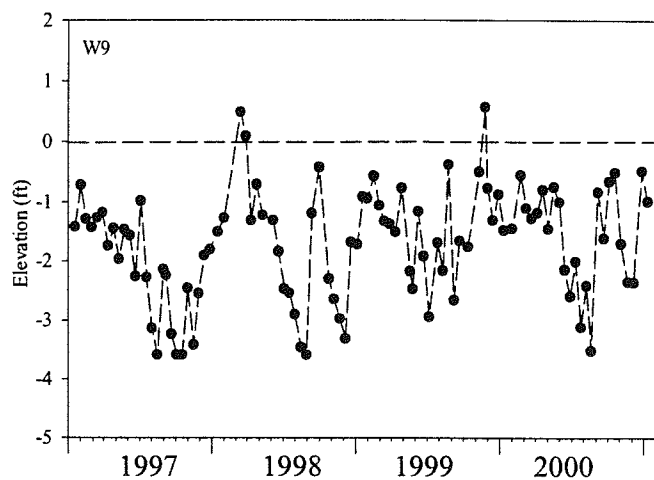
Willie Spruill (Natural Resources Conservation Service) classified soils and provided soil profile logs for the restoration site. Pete Biggam (Soil Scientist, National Park Service) assisted with interpretation of soil profiles and hydrologic characteristics for the study site and the Shoestring Savanna reference area. Ernie Jahnke (U.S. Army Corps of Engineers) advised on compliance with Section 404 of the Clean Water Act and helped install the hydrologic network. Dr. David Cooper (Department of Earth Resources, Colorado State University) provided advice on several of the hydrologic and statistical analyses. We thank all of these participants for their valuable assistance.

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A draft version of this report was reviewed by Ann Childress and Linda Brown (Moores Creek National Battlefield), Lee Pelej (EPA Region IV), Mike Martin (NPS Water Resources Division), Richard LeBlond (North Carolina Heritage Program), and Brian van Eerden (The Nature Conservancy). Review comments were addressed in this final report.



Appendix 1. Water table hydrographs for wells 1 through 14 at Moores Creek National Battlefield, January 1997 - December 2000. Negative values indicate water levels below the ground surface and positive values indicate water levels above the ground surface.



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As the nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.